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part II — summary of information developed in the panel's fact-finding activities

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ANNUAL REPORT TO THE NASA ADMINISTRATOR

by the

AEROSPACE SAFETY ADVISORY PANEL

on the

SPACE SHUTTLE PROGRAM

Part II - Summary of Information Developed in the Panel's Fact-Finding Activities

June 1976

PREFACE

Part I provides an outline of the Panel's most significant observations and assessments based on fact-finding inspections this past year.

This volume, Part II, summarizes the information developed during these fact-finding inspections. It is organized along the lines of the Panel's eight Task Teams. The team approach was used this year to enable the members to focus on areas of Shuttle critical to mission reliability and crew safety. The intent here is to provide the reader with both (a) an accurate description of the data examined including its relevance to the achievement of a safe and successful mission, and (b) a status report on each area with particular attention to the resolution of technical and managment challenges.

Part II of this volume when used with the related portions of the Panel's last Annual Report (June 1975) provides the reader with substantial background on the Space Shuttle's design and expected performance, and many of the critical management systems and organizations. Since the Panel's reviews are cumulative, the statement in last year's Annual Report continues to be true: "This material will be utilized by the Panel in further reviews during the coming year as a baseline and reference manual."

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1.0 INTRODUCTION

1.1 Operational Mode

The Panel's operational mode since its inception has been to conduct monthly inspections by the full Panel. These are held at both NASA and contractor sites. With the completion of the Apollo Soyuz Test Project in July 1975, the Panel was able to focus on the Space Shuttle. As a result, the Panel agreed that they would augment the full Panel inspections with individual fact-finding in areas requiring more intensive review. Thus the Panel held inspections and/or reviewed data at Rockwell International, Downey, California on October 29-30, 1975, at Monsanto Research Corporation in St. Louis, Missouri on December 8, 1975, and at the Johnson Space Center, Texas on February 9-10 and May 24-25, 1976. Members used the time normally allocated for full Panel inspections in September, November, January and March for fact finding research.

1.2 Operational Scope

The Panel's use of a "task team" fact-finding approach as well as full Panel inspections enables the Panel to cover a large number of significant tasks in much greater depth while continuing to monitor the status of the program as a whole. The task areas have been stated in broad terms so that each member can define the specifics of his task based on his analysis of the situation. The task areas are:

a. Systems Integration and Technical Conscience.

b. Space Shuttle Main Engine (SSME).

c. Avionics and its Management System.

d. Risk Management.

e. Ground Test Program and Ground Support Equipment.

f. Flight Test Program (Approach and Landing, Orbital, Ferry).

g. Orbiter Thermal Protection System.

h. External Tank Program and the Solid Rocket Booster Program.

Panel members have assigned themselves to more than one task team to reflect the interdependence or commonality between task areas. In each team one member has accepted responsibility for the team product to assure clear accountability.

The task teams use a variety of ways to obtain the information they feel is necessary to the completion of their tasks. In addition to specific fact-finding visits to the NASA Centers and contractors, they have been attending various in-house reviews as well. These include Quarterly Status Reviews and System Design Reviews. Also, the Panel uses telephone conferences and correspondence with the program offices to assure a thorough understanding of the area under consideration. This also provides the Panel's conclusions and recom-

mendation to the program organizations so that they may make use of the Panel's findings as quickly as possible.

Full Panel inspections provide the forum for members to share their findings and observations.

2.0 SYSTEMS MANAGEMENT

2.1 Introduction

The Panel reviewed those management functions which integrate the project management elements into a program management system and assure integrated flight hardware and software systems. Particular attention was given to those management functions which provide a check and balance on the various project elements and assure a technical conscience. The Panel's last annual report recommended that the "check and balance" capability be further strengthened. The program's response to this recommendation is included as Attachment 2-1. The NASA Deputy Administrator asked the Panel to continue this review of the evolution of these management functions to assure that the program continues to develop a management capability appropriate to the challenge of this program.

Systems management as used here includes the following management functions:

a. Systems integration refers to the management functions which provide for systems engineering, technical integration, and test and ground operations. These management functions include the program level office for systems integration and a large number of technical panels

b. Technical conscience refers to those forums which provide people throughout the organization suitable opportunities to

express their concerns to management. The Panel and review systems are classic examples.

c. Check and balance refers to the technical management capability outside of these day-to-day operations to provide independent assessments on key technical and management issues. The new technical assessment groups are an example.

2.2 Systems Integration - NASA

The systems integration office is involved in defining Shuttle-wide requirements such as (1) the flight dynamics, loads and structural dynamics environment for the total vehicle, (2) the design requirements for such Shuttle wide flight systems as propulsion and avionics, and (3) common requirements and specifications for materials, processes and manufacturing. They are also involved in managing the systems for development of the Shuttle specification and interface documents and monitoring the activities of the individual elements to meet these specifications. They develop trade studies and assessments of proposed engineering changes that affect more than one element as well as participate in working problems that are faced by more than one element.

The office faces a large responsibility and workload and so they have augmented their capability by establishing a systems integration support contractor, and developing a system of inhouse panels and

system management reviews. Their approach is to develop a system which brings together knowledgeable engineering and other personnel from the "line" organizations to work common problems and critique each others efforts and then to manage this system by chartering each group, defining its task/product, and evaluating its processes and results. This also assures efficient use of manpower while giving up some degree of "independent assessment" capability. Among the major management steps this year, MSFC established a Space Shuttle Main Propulsion System Integration Office to review and evaluate the plans and activities for the design and verification of the individual elements and assure that there is an adequate basis for confidence in the end-to-end system from the External Tank to the SSME nozzle.

A "systems engineering plan" is also to be released this year. It will be the single source document on how the systems engineering function in the program is being implemented: (1) what needs to be done, (2) who is doing it, (3) how is it being accomplished, and (4) when it needs to be done. The main text will have the data on the management organizations roles and responsibilities, management techniques and interfaces, task descriptions and implementation, and the expected products and documentation. Appended to this main text will be a set of sub-plans detailing major integrated areas of concern, e.g., integrated schedules, flight performance, loads and dynamics,

guidance, navigation and control.

2.3 Systems Integration - Support Contractor

The contractor has two principal tasks: (a) to assure compatibility of hardware and software for form, fit and function of elements, ground support and facilities, and (b) assure that there is known compliance with the design requirements and performance requirements from a systems viewpoint. This is in effect an expanded configuration control system across the entire program.

The role and principal functional areas involved in this work are as follows:

a. Design engineering deals with subsystem and ground system compatibility along with related software and test requirements.

b. Systems engineering covers mission and operations analysis, trajectory analysis along with thermal analysis and resultant requirements, and flight dynamics requirements.

c. Design integration provides requirements allocation, interface analyses and requirements between hardware and software between all elements of the Shuttle system, and the attendant software, requirements, change analysis to support program and element change control board operations. A special area is the integration of measurements and stimuli for both ground and flight tests and operations.

d. Maintainability seeks to assure that the many elements of the system can be serviced and maintained in the shuttle operational phase once the DDT&E program is complete.

Their activities support and help to produce such items as:

a. System Requirements Definition. The JSC 07700, Level II documents, "Space Shuttle Level II Program Definition and Requirements" and the "Shuttle Master Verification Plan," Volumes I and II.

b. Requirements Analysis. The Contract End Item Specification, Requirements Definition Documents, Volume III of the Master Verification Plan "Orbiter Verification Plan," Test Requirement Requirements' Specifications, Test Plans, Shuttle Operational Data Book

c. Integration Analysis. Integrated schematics, Interface Control Documents (ICD's) for Level II (across elements), Master Measurements List.

d. Compatibility Analysis. Problem reports and their resolution.

2.4 Technical Conscience - Technical Panels

The Systems Integration Office identifies the needs for a panel, charters it and defines the task/product. The engineering organization staffs it, defines the approach and implements it. Over the years the number of panels has grown until there is now at least fifty-four panels. Since these are listed in Attachment 2-2 and the directives

spell out in considerable detail the purposes, responsibilities and procedures the work of the individual panels is not described here in detail. However, one case study is cited here to illustrate how the system operates.

The Manager for Systems Integration is responsible for the integration of propulsion and fluid systems. He in turn has delegated responsibility to the Manager, Systems Engineering Office. The Systems Engineering Manager has established a technical manager for this area and the principal management mechanisms to help him. These include the Main Propulsion System Panel and coordinators to support the manager in the areas of integration of the solid propulsion system and integration of the auxiliary propulsion and fluid systems with other elements of the Shuttle. The Main Propulsion System Panel is responsible for assuring sufficient detailed understanding of the total vehicle to recommend specific overall vehicle requirements, allocation of these requirements to each major element and the interface relationships between elements. The panel by continuous assessment insures that test results satisfy system performance requirements. Through its periodic technical reviews and studies the panel identifies problems, determines corrective action and recommends such action to the technical manager. The systems engineering office maintains contact with the operation of this management system through a desig-

nated liaison officer.

Earlier it was noted that technical conscience implies suitable forums for knowledgeable personnel to raise questions and critique each others work. Many panels by their intercenter and interdisciplinary membership are such forums. The Crew Safety Panel is a classic example. The panel is chartered to assure (1) development of crew safety and crew-vehicle risk assessment requirements for the Shuttle and all its mission phases, (2) identification of individual and integrated subsystem failure modes and hazardous operating conditions which might lead to loss of vehicle or crew, and then (3) identification of modifications in hardware, software, and procedures to reduce or resolve these hazards. Thus they have both policy and operating responsibilities. The membership illustrates the scope of the panel as a forum for it is not limited to safety personnel. Members are drawn from the disciplines represented by the Systems Integration Office, the Operational Integration Office, the Orbiter Project Office, Engineering and Development Directorate, Data Systems and Analysis Directorate (software) Flight Operations Directorate and Life Sciences Directorate. In addition each of the three manned flight centers, as well as the Dryden Flight Research Center with its experience in experiemental aircraft and lifting bodies and the Air Force have members on this panel.

The Systems Integration Office continues to review the structure of the system as well as the operation of individual panels so they can adapt the system to current requirements. This past year they completed a comprehensive review and consolidated some panels where their activities had turned out to be interdependent. For instance, the avionics panel now has responsibility for lightning and EMI effects since avionics may be vulnerable to them. They also identified new needs and established the Ascent Flight Systems Working Group as a senior management group responsible for the trade-offs between the integration of the individual flight systems that are critical during the ascent phase.

The Panel monitors the operation of this system by evaluating the role and contribution of individual panels in areas under review by panel members such as propulsion, avionics and crew safety.

2.5 Technical Conscience - The Review System

The review system also provides a number of forums to bring together knowledgeable people to raise and work concerns rather than let them slip by without the appropriate management attention.

The Shuttle Program Manager has the responsibility to control and manage the overall integration of the vehicle. His personal management tool is the Program Requirements Control Board. The deliberations of this board are supported by the activities and resultant

information provided by the Systems Integration Review (SIR) technical management system.

The SIR's, chaired by the Manager for System Integration, are to assure that specifications are in fact defined and met. These specifications may be for various areas of the environment such as the ascent phase or such integrated systems as avionics and propulsion. Here is a list of the functions to be accomplished by the SIR's.

a. Specification of the ascent flight vehicle systems integrated performance requirements for the Shuttle system and the analysis of integrated vehicle design and test data to assure compliance and compatibility.

b. Specification of the flight performance requirements for the Shuttle system and the analysis of element design and test data to assure compliance and compatibility.

c. Specification of the loads and structural dynamics requirements for the Shuttle system and the analysis of element design and test data to assure compliance and compatibility.

d. Specification of the guidance, navigation and control system performance requirements for the Shuttle system and the analysis of element design and test data to assure compliance and compatibility.

e. Specification of the integrated avionics requirements for the Shuttle system and the analysis of element design and test

data to assure compliance and compatibility.

f. Specification of the integrated propulsion system and fluids requirements for the Shuttle system and the analysis of element design and test data to assure compliance and compatibility.

g. Specification of the requirements for the integrated vehicle attachment, release, and separation systems and the analysis of element design and test data to assure compliance and compatibility.

h. Specification of the integrated thermal design requirements for the Shuttle system and the analysis of element design and test data to assure compliance and compatibility.

i. The development of element-to-element and element-to-ground interfaces and preparation of necessary documentation.

j. Specification of the ground operations requirements for landing, turnaround, launch preparation, and major ground test, including GSE and facilities, and analysis of element design and test data to assure compliance and compatibility.

To exercise control over such a wide range of functions the systems integration office found it necessary to establish technical managers for specific areas. Thus there are managers for flight performance, loads and structural dynamics, flight control integrated avionics, integrated propulsion and fluids, mechanical systems, system interfaces, thermal design integration and ground operations.

The membership of the SIR Board is composed of these technical managers as well as representations from a variety of organization to assure all informed viewpoints are represented. Thus there are representatives from:

Space Shuttle Program Systems Engineering Office, JSC

Space Shuttle Program Operations Integration Office, JSC

Space Shuttle Program Management Integration Office, JSC

Space Shuttle Program Resources and Schedules Integration Office, JSC

Engineering and Development Directorate, JSC

Office of Aeronautics and Space Technology, NASA Headquarters

Space Shuttle Projects Office, Engineering Management Office, MSFC

Science and Engineering, System Analysis and Integration Laboratory, MSFC

Science and Engineering, Systems Dynamics Laboratory, MSFC

Space Shuttle Projects Office, KSC

Orbiter Project Office, JSC

Space Shuttle Main Engine Project Office, MSFC

External Tank Project Office, MSFC

Solid Rocket Booster Project Office, MSFC

Rockwell-Space Division

In addition to these reviews the Systems Integration Office monitors technical progress through attendance at such project reviews

as the ALT design review and the Orbiter 101 and 102 design review. These reviews bring together the knowledgeable people to critique each others work and raise issues. Issues that cannot be resolved at one level are referred to a higher level of management. Management also has the opportunity to review significant decisions made at the lower levels.

For instance, the Approach and Landing Test Critical Design Review completed in April covered in detail the test and test support operations to be performed, the facilities and equipment to be used, and the management and working relationships of the test organizations conducting the approach and landing test program. Further, the ALT Critical Design Review covered the activation of the ALT capability, the conduct of the test program itself, and the deactivation of the program.

The design and manufacturing status reviews for a vehicle enables people to express their concerns about individual flight and ground systems as well as the status of systems integration and reliability, quality and safety work before proceeding to the next phase. These concerns, expressed in the format of RIDs, are officially tracked and formally dispositioned. To give the reader a sense of the issues raised and worked through this system, there were 2400 RIDs identified through the Preliminary and Critical Design Reviews and

Customer Acceptance Reviews on the first flight vehicle 101. Almost all have been worked and closed at this time.

The Panel monitors this area actively by attending selected reviews to evaluate the process as well as issues and their resolution.

2.6 Check and Balance - The Technical Assessment Groups.

It is through the system of technical panels and reviews that technical conscience can find its expression and because people from differing backgrounds can critique one anothers work there is a check and balance and independent assessment process at work. The Panel's recommendation was that this process be further strengthened by personnel outside day-to-day responsibility for the program. This last section describes what the Panel found this year.

Technical Assessment Offices have been established at each of the three manned flight Centers and Rockwell. These are small, well-knit groups of highly skilled engineers who are on the lookout for problem areas to prevent any significant problems from "falling through the crack." These personnel stay abreast of the program and determine their task areas by participating in day-to-day discussions with subsystem managers and working level reviews and discussions using their own personal experience for lessons learned that may be applicable to the current situations.

The program assessment offices are set up as follows:

a. JSC - The office reports to the Shuttle Program Manager and Center management. It defines its own tasks. It has been functioning the longest of the Center offices and has made substantial contribution in such areas as avionics and contingency abort requirements. Currently it has about ten specialists.

b. MSFC - The office reports to the Associate Director, Science and Engineering, and is particularly active in assuring integration of flight systems involving more than one project office. Thus they are actively involved in the work of the Main Propulsion Test Office and Ascent Flight Systems Integration Group. They are still in the process of staffing.

c. KSC - The office reports to the Manager, Shuttle Project Office and is staffed by experienced trouble shooters. The office is still in the process of staffing and getting fully underway.

d. Rockwell International - The Vice President identifies critical areas where foresight and planning now can preclude problems downstream and he staffs as he identifies the need and therefore the expertise required.

So the groups are in place and beginning to function. Next year's report will report on their evolution and their contributions. The Panel monitors this system by working with these groups.

ATTACHMENT 2-1

Systems integration management needs to strengthen "check and balance" capability.

Response: This comment is similar to that made by the Hawkins team. The actions that have been taken include:

a. A special group has been established at JSC to provide an overview of the system engineering/integration function and will report directly to R. F. Thompson, Program Manager.

b. Effort and scope have been increased on the RI/SD contract for system evaluation. A few highly competent individuals are being assigned to provide independent assessments and will report directly to W. Dean, V.P., Systems Integration. The scope of this activity specifically includes problem evaluation and avoidance options, trades, and alternatives; technical and programmatic interrelationships; and contingency planning.

c. A review of the JSC/MSFC panel relationships has been completed and selective changes in membership and panel structure are being made to improve integration across Center/Project interfaces.

d. Program and system level planning is being developed in more detail and will provide more visibility and support to the integration management and decision making process.

SPACE SHUTTLE PROGRAM DIRECTIVES THAT ESTABLISH PANELS, WORKING GROUPS AND SIMILAR OPERATIONS

Directive No.*	Subject
1	Simulation Planning Panel (for simulation activities)
4	Crew Safety Panel
6	Configuration Management Panel
8	Ground Interface Working Group
9	Crew Procedures Control Board
11	Information Management Systems Panel
14	Systems Integration Reviews (SIR)
15	Payloads Interface Panel
17	Program Management Information Center Integration Panel
18	Program Performance Management Panel
21	Flight Test Program Panel
22	Electromagnetic Effects Panel
23	Flight Performance:
	23.1 Ascent Performance Panel
	23.2 Integrated Entry Performance Panel
	23.3 Abort Performance Panel
	23.4 Separation Performance Panel
	23.5 Aerodynamic Performance Panel
24	Main Propulsion System Panel
25	Loads and Structural Dynamics
	25.1 POGO Integration Panel
	25.2 Loads and Structural Dynamics Panel
	25.3 Ground Vibration Test Panel
	25.4 Particles and Gases Contamination Panel
26	Mechanical Systems
	26.1 Spacecraft Mechanisms Panel
	26.2 Shuttle Vehicle Attachment and Separation SUBpanel
	26.3 Payloads Docking, Retention, and Deployment SUBpanel
	26.4 Landing Systems and facilities SUBpanel
27	Shuttle Training Aircraft (STA) Review Board
29	Communications and Data Systems Integration Panel
	29.1 Functional Requirements SUBpanel
	29.2 Vehicle Communications Interface SUBpanel
	29.3 Ground Based Data Systems SUBpanel
	29.4 Science and Engineering Data Processing SUBpanel
30	Flight Operations Panel (FOP)
31	Operations Integration Review (OIR)
33	Computer Systems Hardware/Software Integration Review (CSIR)
36	Training Simulator Control Panel

* Latest Issue

39	Guidance, Navigation, and Control Integration
	39.1 Ascent Flight Control/Structural Integration Panel
	39.2 On-Orbit Guidance, Navigation, and Control Panel
	39.3 Entry Guidance, Navigation, and Control Panel
	39.4 Guidance, Navigation, and Control System Panel
40	Safety, Reliability, and Quality Assurance Management Panel
43	Procurement Integration panel
45	Integrated Avionics Technical Management Area
	45.1 Shuttle Avionics Panel
	45.2 Flight Communications Panel
	45.3 Shuttle Avionics Checkout Panel
	45.4 Avionics Verification Panel
46	Thermal Design Integration
	46.1 Thermal Control Panel
	46.2 Thermal Protection Panel
49	DOD Shuttle Requirements Review Panel
51	Communications and Tracking Systems Ground Test Panel
52	Operations and Maintenance Requirements and Specification Control Board
57	Ascent Flight Systems Integration Group
58	Integrated Logistics Panel
62	Resources and Schedules Management Panel

3.0 SPACE SHUTTLE MAIN ENGINE (SSME)

3.1 Introduction

The Panel has given special attention to the challenges during the past few years, the concerns expressed by NASA management, and the fact the engines are critical to the accomplishment of the Shuttle missions. Specifically, the areas under current review are:

a. The use of new and in many cases unproven technology.

b. Adequacy of design margins to meet the requirements for repeated use.

c. Ability of the engine electronic controller to accommodate the environment and needs of the engine and the total Shuttle system.

d. Results of credible failures.

e. Hardware availability and the test program requirements.

The Panel considered the impact on the hardware and software development program of both (a) cost and schedule constraints, and (b) the numerous interface requirements involving other Shuttle elements such as the Orbiter, Solid Rocket Booster, Ground Support Equipment, and External Tank.

In meeting the objectives of this task the Panel and the task team has relied on briefings, face-to-face discussions with NASA and contractor personnel, participation in in-house reviews, and review

of relevant documents. A part of this effort is a follow-up on open items in the NASA Shuttle Program Office's response to the Panel's annual report The Program's responses to the last annual report on the ngine is included as Attachment 3-1. This material reflects the degree to which analyses and test programs have evolved in providing answers to challenges in the areas of materials behavior under severe environments, weldments, POGO suppression, and controller performance.

A brief look at the Level I (NASA Headquarters) controlled milestones are valuable for they show the program's progress and the work ahead.

- Completed first preburner test	Accomplished April 1974
- Began fabrication of Main Propulsion Test Article (MPTA) Engines for the integrated test of the toal system	Accomplished May 1975
- Completed first integrated Subsystem test	Accomplished June 1975
- Complete first SL firing for a minimum of 60 seconds at Rated Power Level	Scheduled for Feb. 1976
- Complete first throttling test (MPL-RPL)	Scheduled for Mar. 1976
- Complete SSME "all-up" throttling test	Scheduled for Sept.1976
- Critical Design Review (CDR)	Scheduled for Sept.1976
- Delivery of Main Propulsion Test Engines (3 of) to NSTL	Scheduled for May 1977

- Deliver first flight engines (3) Scheduled for Aug. 1978
- Conduct first manned orbital flight Scheduled for Mar. 1979

3.2 Observations

There have been a number of changes in the Rocketdyne organization since last year's annual report. This is readily seen from the comparison of organization charts from September 1974 and October 1975 (Figures 3-1 and 3-2). These changes continue to strengthen the program management system. For instance an Associate Program Manager has been appointed for the engine controller and the engineering areas have been "beefed-up." Mr. Norman J. Ryker was appointed President of the Rocketdyne Division.

3.2.1 Review System

The management system holds a number of reviews on a regular basis. The Quarterly Technical Review for MSFC Senior Management and weekly telecons are two examples. In addition, a special SSME Design Margin Review was conducted in July 1975. Prior to this Design Margin Review, there had been a general concern about the safety factors on many of the components. The margin review showed that most of the components actually had more than the minimum safety factor of 1.4.

Attendance at SSME reviews and discussions with both NASA and Rocketdyne personnel indicate that the review system is working well

in that it provides a forum for frank discussions of technical and management areas and provides necessary information on costs, schedules, and technical performance for day-to-day work and decision-making.

To further assure that nothing "falls through the crack," a technical assessment group has been established and is now being staffed. A Space Shuttle Main Propulsion Systems Integration Office was recently established at the Marshall Space Flight Center to serve as the responsible body for the review and evaluation of Main Propulsion System design criteria and to assure compatibility of Level II/Level III design and performance requirements. They are responsible for the definition and compatibility of mechanical, structural, electrical and fluid interfaces, and design verification of the system.

JSC established a technical manager's position in mid-1974 to oversee the integrated propulsion and fluids technical management areas (Program Directive 24).

To support the Technical Manager they also established the Main Propulsion System Panel. Finally, they appointed a Solid Propulsion Integration Coordinator and an Auxiliary Propulsion Coordinator. The Aerospace Safety Advisory Panel's interests are (a) the Propulsion Panel's achievements in identifying incipient failures including the

means by which early clues to such failures may be determined, and (b) the extent to which prior review RID's remain open, are delinquent or have some further impact not identified previously.

3.2.2 Design Progress

Previously the Panel had raised some questions in the following four areas:

a. Allowable SSME Heat Exchanger Oxidizer Coil Leakage Rate.

b. Use of Teflon Balls in POGO Suppressor Unit.

c. Delays in Receiving and Testing of SSME Components.

d. Data on SSME Controller.

The Program's response to the Panel's concerns are shown in Attachment 3-2.

The Panel was one of those groups interested in getting definitive data on the component design margins to assure that, from a structural and thermal standpoint, the SSME was designed to meet the environmental and time requirements imposed by the overall Shuttle program. The SSME Design Margin Review established the following points:

a. The structural and thermal audits indicated that the current analyses were extensive and technically sound. A few items required further analyses, such as the low pressure oxygen turbopump housing. An example of the factors of safety arrived at during these analyses is shown in Table 3-1. As used on the SSME the definition of

factor of safety is $\frac{\text{Failure Load}}{\text{Limit Load}}$. This accounts for those data points falling within 2σ on the pressure and 3σ on vibration.

b. Many of the design requirements of "one engine out" conditions are still under analysis and test. Consideration has to be given to the expected impact on both the engine that goes out and the other two engines which continue to operate. The following statements are a summary of what we understand the situation to be. It is known that a non-thrusting or shut-down engine will not be cooled sufficiently during ascent so that the engine nozzle will have to be replaced before another mission. This is based on analyses that show a nozzle metal temperature of about 1600° F. versus an allowable of 1200° F. The engines are designed to provide for sensing of critical parameters. The current challenge is to develop the engine controller and the Orbiter flight control procedures that will safely shut an engine down without damage to the other engines or the Orbiter.

c. This review produced a number of recommendations and action items that are currently under active consideration. Among the major ones are: (1) develop data review methods that can be used to identify incipient failures and devise a solution that is practical within cost, schedule and value received boundaries, (2) use maximum throttling ramp rate, (3) limit thrust for early flights to rated power level thereby achieving additional factor of safety

(See Table 3-1), (4) continue to obtain materials properties to assure understanding of the SSME hardware in various environments and in light of life requirements, and (5) increase hardware confidence by conducting tests at higher pressure and temperature levels with added instrumentation.

d. Other recommendations include (1) increase confidence in structural margin by specific burst tests throughout the program, (2) improve fabrication producibility and thereby confidence in the margins of the engine nozzle, the lines and ducts, the hot gas manifold liner and the injector, and (3) improve post assembly inspection procedures.

3.2.2.1 Mass Properties

As in every element of the Shuttle program both the weight specified vs. actual weight and the inertial properties are watched closely for their impact on performance and payload capability. While weights are discussed in terms of an individual engine weight, it is important to remember that these numbers must be multiplied by three since there are three engines on each Orbiter if one is to appreciate the full impact of any design changes. The program monitors three weight values - the contract end item (CEI) value, the design goal weight which is 99.5% of CEI weight, and the control limit weight used to manage the growth rate of the development weight

throughout the program. The table below indicates the latest weight conditions at the time of the Panel's review in January 1976.

Specification Weight (CEI)	6445 lbs. (Dry)	6892 lbs. (Burnout)
Current Weights	6348	6790
Contingency (lbs/%)	97/1.5	102/1.5

This would indicate that stringent controls must be used to assure that by the time of the SSME CDR in September 1976 the weights are still within the specified limits, always keeping in mind that one pound overweight on an engine is in effect three pounds overweight for the Shuttle Orbiter and system.

3.2.2.2 Engine Integration

Not only must the many engine components be designed, assembled and operated as a system, but the engine and its controller must in turn be a part of a well-designed and operable Main Propulsion System within the Shuttle total vehicle. The Main Propulsion System (MPS) includes the External Tank (ET), the Space Shuttle Main Engines, propellant feed, propellant fill and drain, propellant conditioning and pressurization control and purge and the Orbiter interface components. This overall system is shown in Figure 3-3. The following is a brief description of how the MPS operates. The ET provides 1.55 million pounds of usable ascent propellants to the SSME's. Following engine thrust build-up, tank pressure is maintained with vaporized propellants

extracted from the engines. The ET ullage pressures during boost are maintained at 20-22 psia in the LOX tank and 32-34 psia in the liquid hydrogen tank. Pneumatics are supplied by a 4000 psi helium storage system with 750 psi regulation. The helium is used for valve actuation, SSME purge and backup shutdown, expulsion of residual propellants after main engine cutoff. The propellant management controls propellant loading and a low level cutoff which is a backup to the normal velocity cutoff.

The Panel is reviewing the SSME interface to assess whether (1) there is compatibility between the SSME requirements and the MPS, (2) the system/subsystem test programs demonstrate hardware integrity and capability to meet system level requirements, (3) there is schedule compatibility between the design, development and test activities and the availability of hardware , and (4) there is the necessary degree of management and technical liaison between various elements involved in the MPS on issues related to the SSME. While the Panel, including its task team, has not completed its review, its observations to date are noted in both Volume I of this report and in the following sections dealing with the SSME components and assemblies and systems testing. Requirements compatibility will be examined later and the integrated test program will be examined in more detail. Part of this work will be accomplished by participation in Ascent

Systems Design Review Panel operations which are conducted periodically. The last ones were on January 14, 27, and 28, 1976. This was the third such review conducted for the First Orbital Flight Test (OFT-1).

3.2.2.3. SSME Redundancy Management Requirements

Redundancy management deals with control and decision-making necessary to assure the ability of the system to accommodate failures and operate properly. Terms used in this area are defined in Table 3-2. With regard to the SSME the Redundancy Management Requirements have been stated as follows:

a. Fail-Safe Design in the Propulsion System. In the event of any single failure in a functional component, the engine shall be capable of shuting down in a manner which will not damage the neighboring systems.

b. Fail-Safe Design for Electrical Assemblies. All electrical critical subsystems shall be fail-operational after the first failure and fail-safe after the second failure.

Implementation of these requirements can best be demonstrated by looking at typical designs. For the fail-safe design, shutdown of the hydraulic system occurs when a specified limit is exceeded such as pump overspeeds, turbine over-temps, loss of high pressure oxygen turbopump seal pressure or ignition pressure that is either too high or too low. Shutdown of the pneumatic system occurs when there

is a loss of both electrical/data busses for over 50 milliseconds or with the loss of both segments of the engine electronic controller unit. As currently set up the Orbiter can inhibit all the sensors except the ignition pressure detection device and thus has an override capability. To meet the fail operationally/fail safe criterion redundancy has been provided for all critical electrical subsystems. A part of this fail op/fail safe design is the electrical hold-capability to control to the "last" valve position command and a hydraulic hold capability to continue operation at the last valve position. When there is a loss of vehicle/engine commands the system will continue operation at the last valid command and if necessary shutdown the vehicle. The comparison of thrust versus time for hydraulic and pneumatic shutdown are shown in Figure 3-4.

3.2.2.4 Engine Controller

The Panel continues to give the Controller particular attention. From the standpoint of design and development testing, the Controller posture at this time is very encouraging. The major areas reviewed by the Panel included the latest design configuration, test program and results, software and the integration of the Controller into the SSME and Orbiter systems. In addition the SSME throttling requirements and concerns were examined as a part of the SSME control system and Space Shuttle ascent performance.

The Controller design is basically completed with some redesign effort to alleviate problems as they have shown up during the development test program. While the hardware is proceeding through test the software programs are being developed that will both test and operate the SSME and interchange data with the Orbiter vehicle and ground support equipment. The software to hardware compatibility focuses on the computer/memory capability in terms of words and time-to-process input and outputs as well as the expected programming errors and deviations.

Controller design is well into the test phase. Development testing has been continuing using the structural thermal engineering model (SM-1). The production prototype controller (PP-1) has been undergoing a very thorough test process since early 1975 and is now being used in the software development program. Production prototype (PP-2) is now being used in the test program. The Integrated System Test Bed program has been using flight type hardware and the [illegible]-1 rack mounted controller for the numerous test firings conducted over more than ten months at the National Space Testing Laboratory (NSTL). Since the Controller design is in the test and specific redesign period that comes after the basic design and assembly has been completed problems are expected. Most of these have been acceptably resolved.

A major challenge was to protect the Controller from the vibration caused by the total environment system. To screen the PP-2 controller from assembly and workmanship problems, it was subjected to the following

environment: X_2 and X_3 axes at 2g sine sweep, 5 Hz to 2000 Hz up and down for 17 minutes; 6g random duration of three minutes; 2g sine sweep, 5Hz to 2000 Hz up and down for seventeen minutes. At the same time SM-1 was used to develop a vibration mounting for an environment beyond that of the PP-2 tests. PP-2 was then subjected to 25 hours of vibration testing with isolators (intended use) as follows: 22.5 hours (7.5 hr per axis) at 22.5 g RMS, 2.5 hours of transient and sinusoidal vibration, and 120 starts. The overall results were good. Four anomalies were found and all were attributed to assembly/workmanship problems. The causes were determined and the unit was repaired. PP-2 has been delivered to the NASA MSFC Simulation Laboratory for continued testing and SSME operational support. The PP-3 unit with isolators has been delivered and is installed on SSME engine 0002 and successfully operating on test stand A-2 at NSTL with 16 engine tests to date. The vibration test results for PP-3 are as follows:

a. In a soft mounted condition the unit successfully passed 30 minutes per axis of random vibration at 22.5g RMS, 25 starts and cutoffs, and side-load simulations.

b. In a hard mounted condition the unit successfully passed a 10 minutes workmanship test in one axis at 4g RMS and 2g sine.

c. An additional test of 9 minutes at 22.5g RMS was conducted successfully.

The PP-1 controller was subjected to the following vibration conditions earlier in 1975:

a. Thermal tests included 8 hours of operation at -50° F.

and 48 hours of operation at +95^{o} F.

b. Vibration tests included: 3.5 hours sine at 2g and 6g random for acceptance test program; 0.75 hour with 18 to 22.5g random for diagnostic work; 1.5 hours of 22.5g random for Development Verification Levels; and, 8.5 hours of 22.5g random with isolators in place.

c. Functional performance tests to evaluate the "pre" versus "post" test performance ..... pre-thermal test and pre-vibration test followed then by post thermal and vibration tests.

A number of small problems, as noted before, have been encountered and resolved, such as memory noise, cracked solder joints, minor circuit design problems, problems with a number of jumpers and piggy-back components affecting circuit board reliability and some manufacturing difficulties. The problem of electromagnetic interference (EMI) emanating from the power supply may not be fully resolved as yet and will be followed by the Panel.

The current major redesign effort has been directed toward the broken wire problem where so-called "stitch-welding" of wires to pins has been used. The connection would break under the vibration expected on the missions. This is a problem found on both the outboard Master Interconnect Board and the inboard Master Interconnect Board.

The redesign program put into action in December 1975 was in two phases. The first phase completed in February 1976 defined the problem and requirements to the satisfaction of Rocketdyne and MSFC. The second phase, if implemented, is to develop a board design that could eliminate the wiring/weld breakage which has occurred in test vibration environments. Such designs would be directed toward development of multilayer boards to eliminate the wires and hence the wire breakage. If they are used, the multilayer board design can be used on the P-4 and subsequent controllers. If necessary a retrofit can be made on the pre-production units at a later date.

Controller software includes the operational programs, command and data simulator executive program, and controller acceptance test program. The software for the ISTB (Integrated System Test Bed) engine has been in use since May 1975 at the NSTL. The next software to be released is for engine 0002. The Operational Program is scheduled for May/June 1976 and the Command and the Data Simulator Executive Program for March/April 1976. Updates to the 0002 engine operational program is scheduled in two steps - the Block I update by the end of 1976 and a Block II update at an unspecified date.

Software and hardware compatibility aspects of the SSME controller will continue to be studied in an effort to provide proper margins and process times. The current situation looks like this:

SOFTWARE FOR	Memory Size (16,384 words) UTILIZED	BUDGET	Process Time (20 milliseconds) UTILIZED	BUDGET
ISTB	14,595	-	17.36 ms	-
ENGINE	15,270	-	18.4	-
BLOCK I (Pre Scrub)	20,040	14,000	18.265	16.0 ms
BLOCK I (With Scrub)	13,585	14,000	13.63	16.0
BLOCK II (Prel. Est.)	14,700	14,700	15.18	16.0

Software scheduling problems include the availability of Honeywell personnel and facilities to support NSTL operations on simulation runs and software changes for the ISTB program, and an even more severe condition when two of the NSTL test stands are operating at the same time. The available support for the current multiple software program (ISTB changes into the 0002 software and those within the 0002 programs) is also a problem due to manpower and facility availability. The impact of this scheduling difficulties will be an area of continuing review by the Panel.

3.2.2.5 SSME Hardware Components

A discussion of the design progress of the engine components and assemblies at this point in the program must focus on the development and acceptance test programs since the engine design is basically complete. What design work is still going on is more in the line of

redesign and upgrading of designs based on test results. Therefore these areas of design are covered in the next section on "Test Program and Plans" or in the section on "Manufacturing."

3.2.3 Test Program Plans

The engine development program consists of a Design Demonstration Phase and a Certification Phase. The design demonstration activity is scheduled to be completed by the SSME Critical Design Review (CDR) in September 1976. This CDR will cover the completed and released design, the basic engine concept and the tests to demonstrate their validity. The certification activity will then include work necessary after CDR to successfully complete the Preliminary Flight Certification scheduled for November 1978 and the Final Flight Certification scheduled for Spring 1980.

Testing during the design development and demonstration phase includes laboratory testing as well as subsystem and engine hot-firing testing.

The laboratory testing is performed at all hardware levels to accelerate the verification process and to minimize hot-fire tests by detecting problems early at the fundamental part level. The test program includes basic mechanical tests to verify material properties, dynamic tests of turbopump bearings in the operating fluid at full operating speed, and simulation of engine operational checkouts and

maintenance. Since laboratory tests are extensive, they provide confidence in many areas: (1) mechanical, (2) vibration, (3) flow, (4) environmental, and (5) functional.

Subsystem hot-fire testing is concentrated on the verification of those requirements and assumptions for which the engine environment is not required. Included in this test program are the ignition system, preburner, turbopumps and combustion assembly.

The third element in this test phase is the hot-fire testing using the Integrated Subsystem Test Bed (ISTB) - an engine with a development nozzle and breadboard controller. The ISTB program objectives are:

(a) Development of the engine control.system.

(b) Extended-duration testing of the oxidizer and fuel turbopumps.

(c) Hot-fire verification of the engine hot-gas manifold.

(d) Verification of engine starts, shutdown, and throttling throughout the range from minimum power level (MPL) to rated power level (RPL).

(e) Supplementary verification of preburner and turbopump requirements.

The ISTB with its controller provides control system and transient performance verifications as a supplement to engine testing. Thus

there is a demonstration of basic system integrity prior to the first engine test.

Following the ISTB tests, hot-firing tests are scheduled at NSTL to (1) test equipment, and (2) to extend the power level to full power level (FPL). Equipment to be included in these tests are gimbal actuators, inlet ducting, and interface panels for fluid, electrical, and thermal protection. Testing at sea level conditions will range from RPL to FPL. A test stand nozzle diffuser at NSTL allows operation of the engine between MPL and RPL.

An integral element of any test program plan, including that for the SSME, is the series of Design Verification Specifications (DVS) because these define the development plan for the engine system, subsystems and components. Table 3-3 lists all of the current DVS's. Section 3 of these documents contains the design requirements while Section 4 contains the verification methods, hardware levels, and other criteria necessary to demonstrate that each design requirement has been satisfactorily met. In addition to the DVS's development plans there are special plans for "life demonstration" tests to ensure that a conservative margin is maintained and plans for "hardware recycling" in which test components and assemblies are made up of "new" and "recycled" units. Also, there are materials evaluation plans for the selection, development, and specification of all materials

and processes for the SSME.

3.2.3.1 Test Status and Results

The ISTB has been in a hot-firing condition since May 1975 at NSTL on test stand A-1. Engine 0002 has begun hot-firing at stand A-2. Engine 0003 when ready will take over the A-1 stand in mid-summer of this year. All of these tests, on the ISTB and 0002, are expected to be nearly complete by the time of the SSME CDR in September 1976.

3.2.3.1.1 ISTB

Well over 60 tests have been conducted to date. The next significant milestone is the achievement of a sustained 60-second engine firing at rated power level. This test has been delayed somewhat because of the time required for the resolution of engine transient and high pressure fuel turbopump development problems as well as a flow-meter problem on an installation at the COCA stands at Santa Suzanna, California. As soon as these are resolved the 60-second test will be accomplished. Another milestone will be the throttling test to be conducted in the midsummer with the power level from MPL to RPL. Further throttling tests are also scheduled for the period starting about August 1976.

So far the ISTB has been run at 76% of RPL for more than 20 seconds.

Some of the problems that have surfaced have been resolved or are under intensive study, include the following:

a. The main fuel valve assembly follower bearing side-plate cracked during the ISTB tests. Cracks were found on the inner race section of the plate. The original 440C material was replaced with Inco 718 as an interim redesign. If necessary the redesign will be refined at a later date.

b. Electrical "pig-tails" are subject to environmental abuse and failures so a new connector design will be effective on engine 2004 and subsequent.

c. Preburner, LOX and fuel, temperature spikes were a problem during the conduct of the first 29 ISTB tests. Modifications have been made and proven on subsequent tests.

d. The low pressure fuel turbopump inlet/outlet duct consisting of a flexible bellows joint has had leak problems. Rocketdyne is investigating a number of fixes. For the present they have decided to incorporate a brazed design bellows on engine 0003 and subs, while continuing to use the existing ducts on the first two engines (ISTB-0001 , 0002). Indications are that the early-type flex ducts can withstand the rigor of continued firing in order to meet test requirements.

3.2.3.1.2 Engine 0002

This engine has just begun its test cycle at NSTL with 16 tests conducted to date. Early testing has evaluated the start characteristics, while the most recent testing has evaluated fixes to the high pressure fuel turbopump.

3.2.3.1.3 Component Tests

For our purposes the components of the SSME include combustion devices, turbomachinery and the controller. Previous sections have discussed the controller.

From a standpoint of the critical hardware for the 0003 and 0004 engines, the following problems exist. On the 0003 the bellows assemblies mentioned above have been brought "in-house" due to vendor problems which in turn has resulted in some changes to the schedule completion dates. However, there appears to be little or no impact from this delay since there is a pad of some six weeks available. Engine component problems on the 0004 include the high pressure fuel turbopump, the main combustion chamber, and the 77.5:1 nozzle. This engine is due for delivery around September 1976. To help mitigate these problems Rocketdyne has completely revamped its so-called "pump assembly room" at Canoga Park to do a more orderly and timely job on turbomachinery.

3.2.3.1.3.1 Combustion Devices

A testing summary is shown in Table 3-3 covering the following

items:

Augmented Spark Igniter (ASI)

Oxygen Preburner (OPB) and Fuel Preburner (FPB)

Thrust Chamber Assembly (TCA)

Heat Exchanger

Nozzle with 35:1 Ratio

The 40,000 pound thrust scale model was used for tests at MSFC.

In summary, the combustion devices test program indicates that the above items have been operating satisfactorily. Problems that have cropped up during the test program have either been resolved to the satisfaction of the designers or a resolution is now in process. For instance, the 35:1 nozzle TCA tests conducted at COCA 4B show an excessive pressure drop existing between the inlet diffuser of the main combustion chamber, the tubes, and the mixer at the outlet. The measured pressure drop was 544 psi while the predicted was 349 psi resulting in an excess of 195 psi. These measurements were at RPL. The impact on engine balance results in tube life decrease and engine temperature increases. This problem is under active investigation at this time with results expected soon.

The Augmented Spark Igniter (ASI) has experienced spark plug tip overheating resulting in erosion and cracking of the plug tip. This problem is being worked by developing a copper-plating process, controlling the ISTB hydrogen temperature on engine start, eliminating temperature spikes during any transient and using the copper-plated

plugs on the engines when they become available.

Steps taken to prevent other combustion device fabrication problems include prevention of pitting in the main combustion chamber liner by revising tooling for the electroform process and prevention of the 77.5:1 nozzle braze and weld problems by redesign of the manifold shell and modified tooling for brazing process.

3.2.3.1.3.2 Turbomachinery

The significant results of the turbomachinery tests are:

Low pressure oxygen turbopump	Tested to Full Power Level
Low pressure and high pressure oxygen turbopump	Tested to RPL (Transition) Tested to 0.92 of RPL (Steady-State) Impeller performance defined
Low pressure fuel turbopump	Tested to FPL Performance Mapped Bearing failure experienced
Low pressure and high pressure fuel turbopump	7 tests, tested to 0.75 of MPL Axial thrust balance difficulties resolved; speed limitation on HPFTP because of subsynchronous whirl
High pressure oxygen turbopump Seals and Bearings	Borg-Warner wear problem investigated Testing initiated on "Sealol" Seal

The problems noted can be described as follows:

(a) The LPOTP housing had failures during the RPL proof test. Inspection of the casting is a difficult task. As a result, the problem is being approached from both a materials aspect as well as providing a more thorough inspection process.

(b) The HPOTP impeller performance has been lower than expected at the RPL condition. This appears to have resulted from

impeller vane resonance and resulting lowered outlet head. Modifications of the impeller are being made and further testing will confirm the redesign.

(c) The HPFTP rotor axial thrust balance problem has been the cause of axial rubbing and damage during tests of this pump. The problem is recognized and understood. A step-by-step procedure has been followed to balance the rotor system such that during running conditions the system will be balanced by means of internal orifices and preclude overspeeding and rubbing of parts. The rotor system has been balanced in tests up to 75% of RPL. Additional tests up to full power level must now be conducted to confirm the design.

(d) The high pressure fuel turbopump subsynchronous whirl problem has been the cause of excess shaft vibration and turbine bearing load failures. A step by step procedure is being followed to reduce the vibration level so that long duration engine tests can be conducted above the 60% RPL. Moderate improvement from immediate fixes has raised the whirl inception speed and reduced the severity of the vibrations. However, to completely resolve the problem and enable the pump to run up to full power level, a stiffened rotor and support system plus moving the pump and bearing inboard will most likely be required.

(e) The HPOTP primary LOX seal has had inadequate life due to excessive wear. There is no immediate problem on the engine test stands; however, steps are being taken to reduce the load on the seal and provide a better seal material in the future.

3.2.4 Manufacturing

Since manufacturing is discussed in varying degrees in the preceeding sections on review, design and test of the SSME and its components, the discussion here is limited to four items that are of major interest at this time: (1) the increase in the turbopump assembly area and facilities at Rocketdyne, (2) machine tool requirements and rehabilitation program, (3) welding, and (4) pre-production in-house fabrication maturity. The turbopump assembly operation is

being expanded so that it can handle eight assemblies simultaneously. This requires increased supervision, mechanics, and quality control; duplicate tooling; three-shift operations in most cases; and, a setting up of a standardized assembly or flow process to optimize the use of men and equipment. The machine tool study is also a step in making the very best use of on-hand equipment. Welding has been a consistent problem on the more complex configurations used in the main combustion components and some turbopumps as well as the full-size 77.5:1 exit nozzle. Quality of the welding is being improved by a program to use automatic welds rather than manual welds and upgrade the machines themselves. The following is a list of weld changes from manual to automatic in the course of the period between October 1975 and February 1976:

	10/9/75	1/15/76
Ducts	66	15
Turbopumps	7	0
Main Combustion Chamber	3	0
77.5:1 Nozzle	1	2
Hot Gas Manifold	3	2

It is understood that the first "good" 77.5:1 nozzle has completed its fabrication cycle with minimum weld distortion which indicates that particular problem may be resolved.

3.3 Addendum

ISTB testing with the reworked Low Pressure Fuel Turbopump was restarted at the end of May and testing at the COCA IB facility has been resumed as well.

Accelerations, vibrations and unbalanced forces on the rotating shaft and blades of the High Pressure Fuel Turbopump have caused premature engine shutdown a number of times. This appears to be the result of subsynchronous whirl effects or pressure oscillations at frequencies near 50 to 55% of the actual pump speed itself. To resolve this problem, outside specialists have been consulted; a literature search of hundreds of publications and speciality texts from several nations has also been started. The most promising fixes appear to be increased Coulomb damping on the bearing carrier; a tangentially vented pressure relief interstage seal; reduced interstage seal length; reduction in shaft hysteresis; decoupled axial and radial modes; and, of course, any combination of the above modes.

The SSME System Safety activities currently underway includes an update of the SSME hazard summary listing all identified hazards and causes; preparation of the final report on the NSTL hazard analysis for the A-1 and A-2 test stands; and the planning of an oxygen fire symposium to assure test personnel are up to date on the current safety provisions.

The P-4 engine controller assembly is on schedule. Power supplies for this unit have successfully passed a 10 minute, three axis subsystem vibration test. The P-4 controller is due at Rocketdyne in September 1976.

ATTACHMENT 3-1

The major challenges of significance for crew safety on the Space Shuttle Main Engine are materials behavior under severe environments, weld integrity, POGO suppression, and engine controller performance and reliability. Therefore, the results of the test program will be critical to developing confidence in these areas.

Response: SSME Materials Behavior Under Severe Environments

(a) An extensive analysis and test program is well underway. The fracture mechanics test program has been expanded to include more materials and components. Fracture mechanics analyses include load cycling and environmental conditions, alloy/condition combinations, weld combinations, and the effects of coatings and weld overlays. These analyses will be verified by the test program. Minimum detectable flaw sizes will be established by non-destructive methods. In addition, an assessment of the structural margins in the SSME with regard to structural, weight, and performance requirements was conducted by a high level team composed of members from JSC and MSFC. All 117 components reviewed meet the engine safety factor requirement of 1.4 at full power level, and 88 of these meet a 1.5 safety factor at full power level.

SSME Weld Integrity

(b) Fabrication of the first engine and supporting components revealed areas requiring improvements in weld integrity. Extensive action has been taken in the area of weld analysis, redesign of some weld joints, converting from manual to automatic welding, evaluating of process parameters, upgrading/increasing staff, upgrading equipment and improvements in inspection and quality control procedures to assure good welds.

POGO Suppression

(c) A continuing analytical program is underway and being pursued to understand the POGO phenomenon and its implications to the SSME by NASA field centers and their contractors. A POGO integration panel, chaired by Dr. Harold Doiron of JSC, has been in operation since June 1973, to continually review analytical and test data. The POGO suppressor has been baselined and a comprehensive test program on individual component parts is already underway. Engine tests will verify the POGO suppressor system. Extensive use has been made of Saturn data in designing the test program.

Engine Controller Performance & Reliability

(d) High priority by top management at Honeywell, Rocketdyne, MSFC, and Headquarters is being applied in this area. Because of current problems with the controller interconnect system (inboard master interconnect system) and the fact that it is difficult to

manufacture and reproduce, two studies have been initiated on an interconnect redesign effort as a product improvement. Furthermore, we are proceeding to mount the controller on isolators (shock mounts) which significantly reduce all vibration energy into the controller at frequencies above 100 Hertz. In addition, RTV potting and foam have been added to the inboard master interconnect board to reduce wire stress concentration and dampen the wires dynamics. It should be noted that the wire breakage problem we have encountered has been associated with the inboard half of the controller interconnect system, and not the memory plated wire.

ATTACHMENT 3-2

Allowable SSME Heat Exchanger Oxidizer Coil Leakage Rate

We are glad that they are keeping an open mind on this since a leak rate of 10^{-3} cc/sec helium during field operational leak test inspection sounds like a fairly large crack. This is a critical piece of gear. Is this a case where the 160 hour turnaround time is the driver?

Answer:

The heat exchanger leakage rate test requirement for launch operations has not been firmly established. The 1×10^{-3} cc/sec helium check is being used for planning purposes. The necessary leak check and/or any other inspection requirement will be based on the development experience and the assessed risk of a failure. The 160 hour turnaround requirement will no doubt be a consideration in all ground operation planning but will not be the deciding factor.

Use of Teflon Balls in POGO Suppressor Unit

What are the requirements for the ground tests to verify this design? How closely can they approximate flight conditions?

Answer:

The hollow teflon balls utilized in the POGO suppressor will be subjected to extensive testing as individual parts as well as in component tests. They will also be utilized and subjected to operating conditions during all engine testing subsequent to incorporation of the suppressor into the R&D program. Being an internal part of the engine system, the teflon balls should be subjected to operating conditions which closely simulate flight conditions. The only known difference will be operation in a 1-g environment as opposed to a flight environment of up to 3-g's. It is not anticipated that this difference will have an effect on the operation of the balls.

Delays in Receiving and Testing SSME Components

What is the nature of these problems? What is the impact on the NSTL test program?

Answer:

The SSME Project is experiencing delays in the manufacture of hardware similar to that experienced on previous engine development programs. The delays are indicative of the complexity of the various manufacturing processes involved and the development learning cycle. However, at this time approximately three specimens have been made of all hardware items, except for the 77:1 nozzle scheduled for completion in early CY76. The initial specimen experience and the hardening of the tooling continually improves the hardware schedule visibility. The testing of components and the engine system is not being driven by the hardware schedules and adequate hardware exists to perform the tests as the test facilities and engineering planning allow.

SSME Controller

When do you expect to have the necessary information on the problems with the current Controller to make a decision on the backup unit? What kinds of information will be considered?

Answer:

The test experience with the first prototype controller (PP-1) and the ISTB experience with the rack mounted controller (EM-1) and its software, have eliminated the need for further backup controller planning. While some changes are being considered to reduce sense line noise and to reduce fabrication problems with the Master Inter-connect Board (MIB), considerable experience has been accumulated through functional and environmental tests of PP-1 and through the ISTB tests conducted to date at NSTL. While long duration testing at environmental extremes is still to be completed over the next few months, the functional and short test duration thermal and vibration data accumulated to date indicates that the present controller can be made to function within the engine program constraints. Closure of the backup controller contingency planning effort is presently being staffed between Level II and Level I.

(The November 1974 Contingency Plan for SSME Controller identified a target date of early July 1975 for making a decision on this subject based on projected availability of testing experience and procurement lead times. At the time of our review with the Panel, late April, the test and manufacturing experience accumulated with PP-1 indicated that backup controller effort would not be required.)

TABLE 3-1

FACTORS OF SAFETY FOR SSME

AT FULL POWER LEVEL VS. RATED POWER LEVEL

SSME HARDWARE ITEM	Factor Of Safety FPL	RPL (Calculated)
Low Pressure Oxidizer Turbopump		
Housing	1.50	1.67
Inducer	1.50	1.67
Turbine Blades	4.40	4.90
Turbine Stator Vanes	1.42	1.58
Shaft	1.69	1.69
Low Pressure Fuel Turbopump		
Turbine Housing	2.12	2.29
Pump Housing	1.53	1.64
Inducer	2.74	2.90
Shaft	1.91	2.02
High Pressure Oxidizer Turbopump		
Second Stage Turbine Blades	1.76	2.03
First stage Turbine Disc	1.48	1.71
First stage Turbine Nozzle	2.27	2.50
Turbine bellows	1.69	1.97
Turbine Fairing	2.28	2.67
Turbine Exhaust Struts	1.50	1.75
Turbine Inlet Housing	1.65	1.93
Pump Housing-Inlet	1.62	1.89
Discharge	1.62	1.70
Diffuser Vanes	1.41	1.50
Preburner Volute	1.59	1.70
Main Shaft	1.50	1.75
High Pressure Fuel Turbopump		
Second Stage Turbine Blades	1.40	1.49
Second Stage Turbine Disks	1.40	1.49
First Stage Turbine Nozzle	1.83	1.96
Second Stage Turbine Nozzle	1.55	1.66
Turbine Bellows	1.53	1.64
Turbine Bearing Thermal Shield	1.76	1.89
Turbine Bearing Support	2.66	2.86
Shaft System	1.46	1.53
Pump Housing-Mount'g flange	1.50	1.61
Discharge	1.82	1.94
Diffuser Vanes	2.12	2.26
Pump Inlet vanes	2.00	2.20
Third Stage Impeller	1.79	1.91
First Stage Diffusers	1.50	1.61

TABLE 3-1 (continued)

	FPL	RPL
Valve Actuators		
Connection Flange	1.40	1.40
Pressure Cylinders	2.00	2.00
Gimbal Bearing		
Body	1.48	1.57
Shaft	1.64	1.64
Seat	1.47	1.47
Hot Gas Manifold		
Shell	1.42	1.56
Injector Weld	2.08	2.29
Fuel Preburner Weld	1.55	1.70
Oxidizer Preburner Weld	1.45	1.59
Fuel-Side Collector Liner	9.-	9.-
Fuel-Side Transfer Tube Liners	1.75	1.75
Oxid-Side Collector Liner	2.90	2.90
Oxid-Side Trans. Tube Liners	4.22	4.22
Heat Exchanger Weld	2.70	3.00
Main Combustion Chamber		
Actuator Struts	1.41	1.41
Inlet Manifold	1.41	1.48
Discharge Manifold	1.47	1.55
Longitudinal Welds	1.40	1.50
Liner- Electro Deposit Ni	1.60	1.79
- Narloy-Z	2.29	2.54
Acoustic Cavity	2.61	2.83

TABLE 3-2

REDUNDANCY MANAGEMENT DEFINITION

● REDUNDANCY	- REFERS TO HOW OFTEN A FUNCTION IS REPLICATED
● REDUNDANCY MANAGEMENT	- REFERS TO HOW MONITORING & CONTROL OF REDUNDANT FUNCTIONS ARE PERFORMED
● FAIL OPERATIONAL (FO)	- MISSION OBJECTIVES CAN BE ACCOMPLISHED AFTER A SINGLE FAILURE
● FAIL SAFE (FS)	- SAFE VEHICLE & CREW RECOVERY AFTER SINGLE FAILURE
● FO/FS	- FO AFTER FIRST FAILURE & THEN FS FOR ANY SUBSEQUENT FAILURE WITHIN THE SAME SUBSYSTEM
● FDI	- FAULT DETECTION & IDENTIFICATION (AND ANNUNCIATION)

TABLE 3-3

DESIGN VERIFICATION SPECIFICATIONS
(DVS)

Specification Title	Specification Number
Engine System	
Main Engine (Vols. 1,2)	SSME #101
Gimbal Bearing Assembly	102
POGO Suppression System	106
Avionics	
Controller Assembly (Hardware Vol. 1, Software Vol. 2)	201
Electrical Harness	202
Instrumentation System	203
Flowmeters	204
Ignition System	205
Combustion Devices	
Thrust Chamber Assembly	303
Hot-Gas Manifold	304
Fuel and Oxidizer Preburner Assemblies	305
Turbomachinery	
Low Pressure Oxidizer Turbopump Assembly	401
Low Pressure Fuel Turbopump Assembly	402
High Pressure Oxidizer Turbopump Assembly	403
High Pressure Fuel Turbopump Assembly	404
Valves and Interconnects	
Check Valves	508
Pneumatic Control Assembly	510
Flexible and Hard Duct and Line Assemblies	511
Hydraulic Actuation System	512
Heat Exchanger	513
Static Seals	514
Propellant Valves	515
Fuel and Oxidizer Bleed Valve Assemblies	516
POGO Suppression System Valve Assemblies	517

TABLE 3-4

COMBUSTION DEVICES - TESTING SUMMARY
(THROUGH APRIL 1976)

	TESTS COMPLETED	TESTS PLANNED TO CDR	
ASI	28 TO FPL 700 ENG. START	FULL DURATION	4 TESTS
OPB & FPB	19 TO FPL	2ND UNIT PERF. & DURABILITY (MAX. CONDITIONS) STABILITY	32 TESTS
TCA	17 TO FPL	BOMB DEVELOPMENT (PHASE B TCA)	5 TESTS
		STABILITY & DURABILITY (MAX. CONDITIONS)	11 TESTS
		2ND UNIT PERF. & DURABILITY (MAX. CONDITIONS)	10 TESTS
40K	102 CYCLES RPL (MCC)	40 ADD'L CYCLES ON INJECTOR	28 TESTS
NOZZLE	17 TO FPL (35:1)	77.5:1 FPL OPERATION (MAX. CONDITIONS)	3 TESTS
HEAT EX.		PERF., DURABILITY & FLOW STABILITY	10 TESTS

FIGURE 3-1

SPACE SHUTTLE MAIN ENGINE PROGRAM

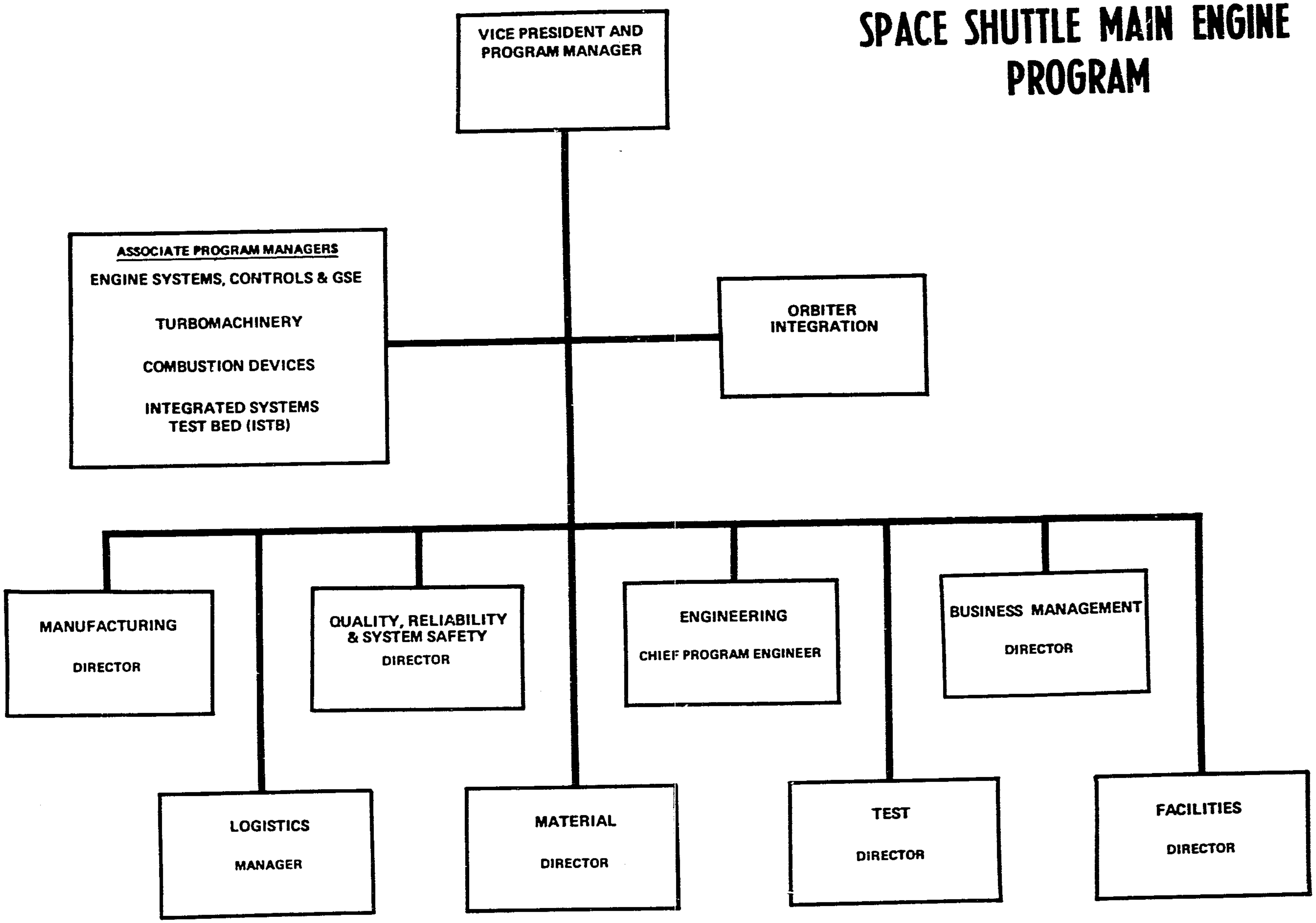


FIGURE 3-2

SPACE SHUTTLE MAIN ENGINE PROGRAM

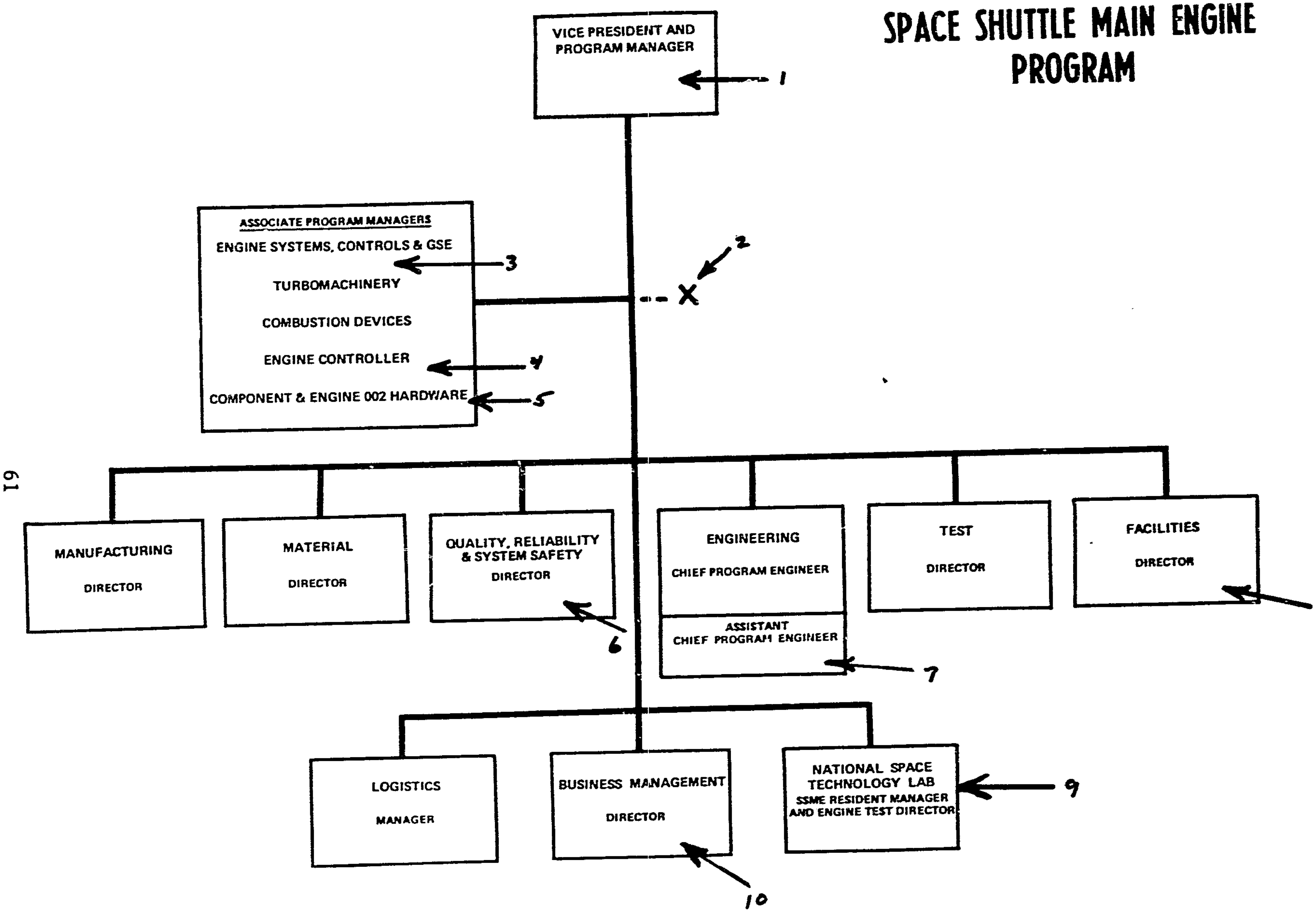


FIGURE 3-3

MAIN PROPULSION SUBSYSTEM SCHEMATIC (FLUID)

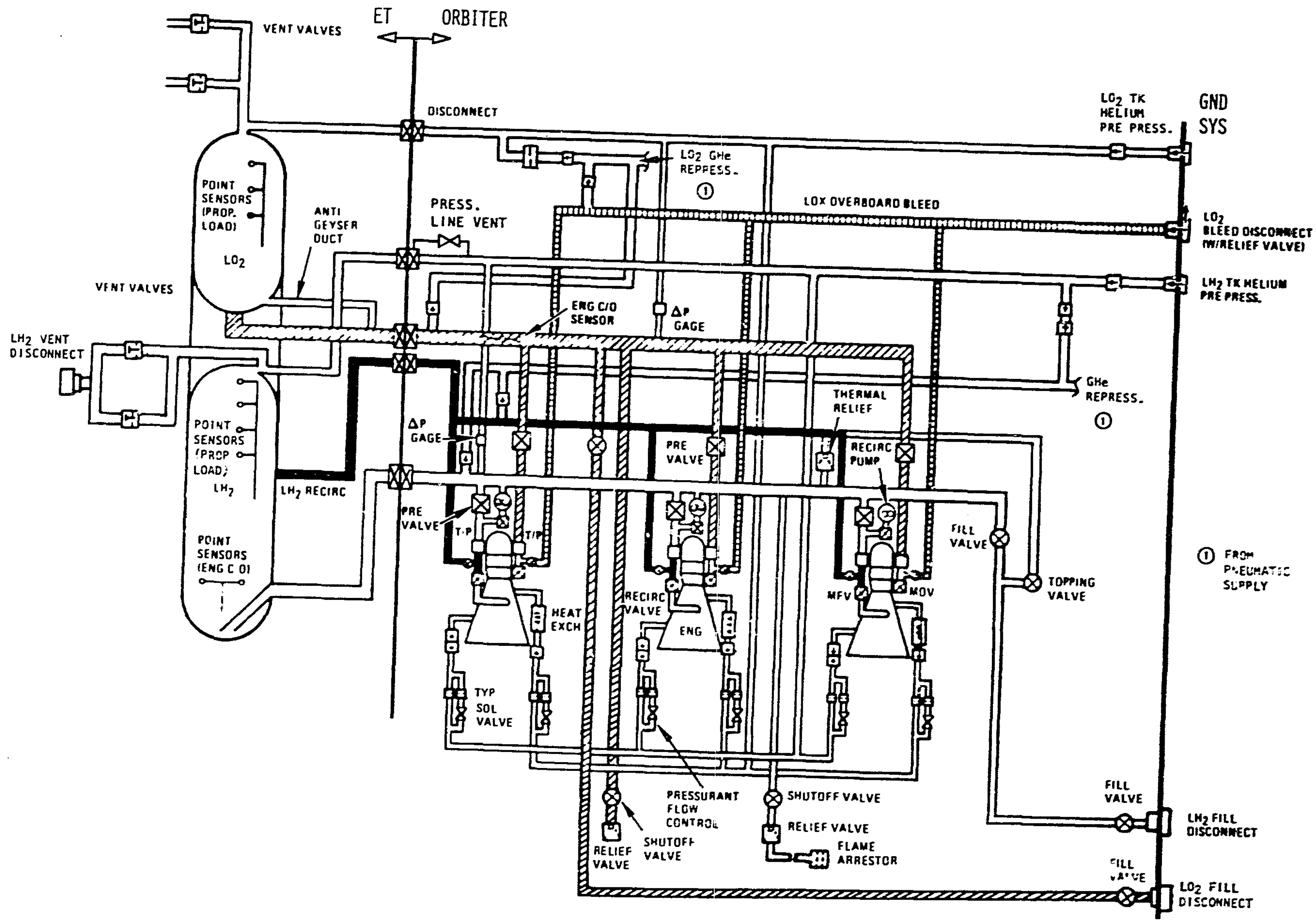
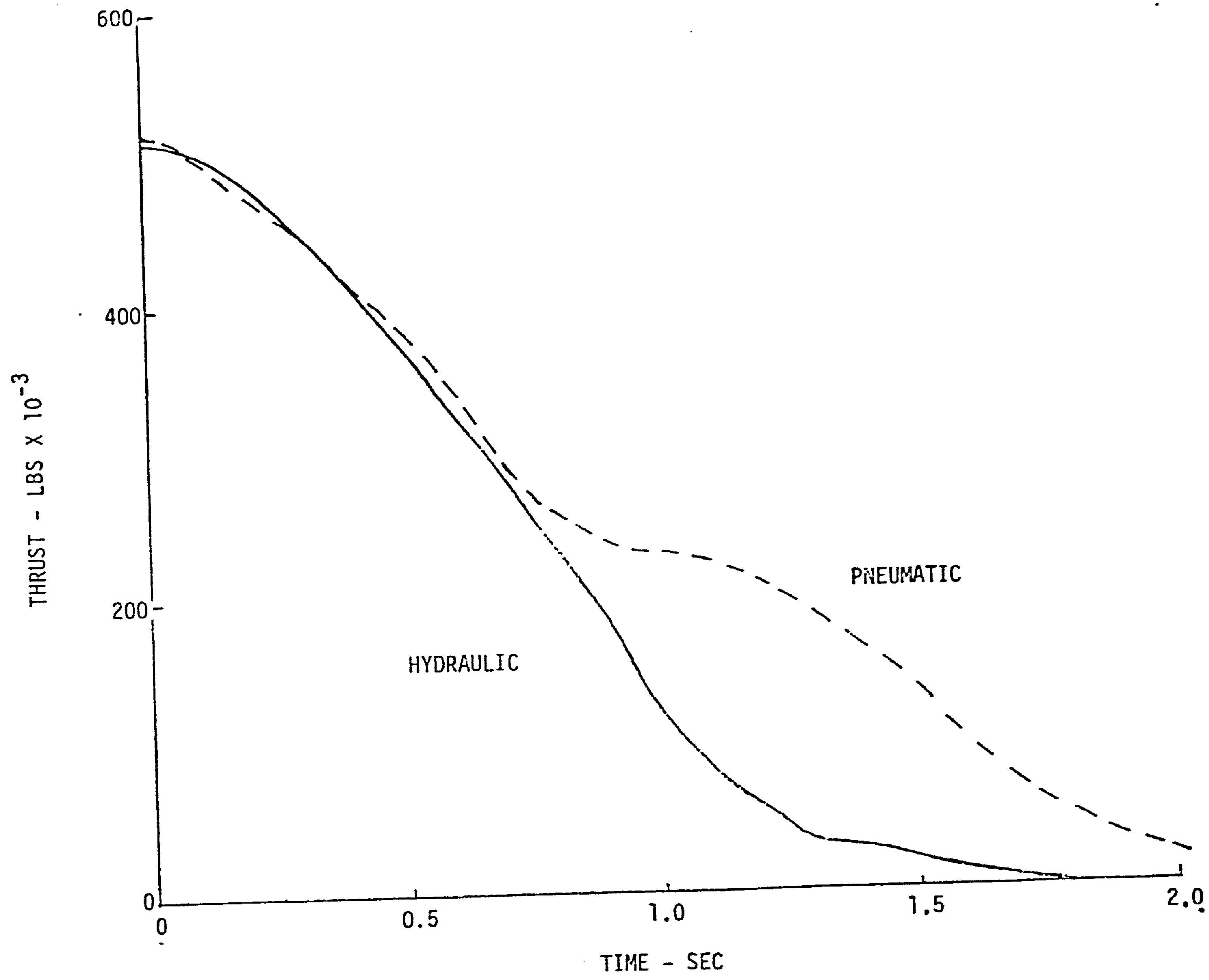


FIGURE 3-4 HYDRAULIC VS PNEUMATIC SHUTDOWN



4.0 ORBITER THERMAL PROTECTION SUBSYSTEM

4.1 Introduction

The Orbiter 101 Critical Design Review and the Orbiter 102 Preliminary Design Reviews have resulted in a reasonably firm baseline of the Orbiter Thermal Protection Subsystem (TPS). As a result, detailed drawing releases, fabrication of hardware, detailed tests, have all begun. The Panel reviewed both the management systems and their implementation as well as the technical adequacy of the TPS. Given this new technology, the Panel wants to assure an adequate basis of confidence in reliability of the TPS and therefore crew safety.

The Panel has had this critical Shuttle hardware system under review during the past two years as shown in Table 4.1. The Orbiter TPS is, of course, a many-faceted system of the Orbiter. It is affected by many factors: aerodynamic pressures; structural deflections on the Orbiter; and the External Tank and Solid Rocket Booster elements of the Shuttle Cluster. Given this complexity it was apparent that the Panel could not provide detailed scrutiny of all these aspects. Therefore the Panel and the Task Team focused on (a) the technical requirements for the TPS during phases of the Shuttle mission, (b) those features of the TPS most affected by unique mission requirements, operational restrictions, resource reductions, (c) challenges created in using new technology, and (d) flight test requirements not previously experienced on manned space flights.

The Panel examined the management systems in terms of its inherant capability for handling (a) communications between technical personnel and through senior levels of management, (b) the hazards identified and their resolution and risk assessment, (c) such major technical problems and interface effects as design, test, fabrication, logistics, maintenance, and assembly. Technical areas covered in these discussions covered materials and processes, thermal analyses, structural adequacy, systems integration, TPS and Orbiter hardware properties affected by aerothermodynamics of ascent and reentry.

Many parts of the program impacting the TPS are under review by the Task Teams for such areas as the Shuttle Major Ground Test Program, Approach and Landing Test Program, the Orbital Flight Test Program, Development Flight Instrumentation, External Tank and Solid Rocket Booster Programs, and Risk Assessment.

The fact-finding began with detailed preliminary data collection and analysis resulting in a discussion with appropriate program personnel to establish the specific areas of interest, the personnel that should be involved and the best sites for the discussions. Then the team undertook on-site reviews with various levels of working and management personnel and examined as appropriate the hardware/software, tests, and documentation.

The team then reviewed the program response to their action item

and subsequent baseline reviews and test results. This report is based on such activities.

4.2 Observations

4.2.1 Organization

There have been no measureable changes in the management organization of personnel since the Panel's last report to the Administrator dated June 1975. Based on discussions with NASA and contractor personnel the organization appears to be operating well and is producing the necessary communication between all levels. Top management has visibility of the overall status of the TPS program. The Panel will continue to review the ability of the various TPS organizational elements to respond quickly to changing program needs when they are defined at the Orbiter 102 Critical Design Review and as a result of the updated "loads programs."

4.2.2 Review System

The Orbiter Thermal Protection Subsystem Design Review conducted from mid-July through mid-August 1975 was an extension of the Orbiter 102 Preliminary Design Review (PDR). Since this is a good example of the depth and scope of such a review, the following particulars on the process are cited:

July 28th	Data Packages after having been checked and assembled were sent to

	participants for critique at the following locations: JSC, KSC, ARC, LaRC, NASA Headquarters, SAMSO.
July 28 - August 8	The data was reviewed and Review Item Dispositions (RID's) were submitted as a result of this critique.
August 12-13	The Screening Group reviewed all RID's, resolved the technical or management questions where appropriate and identified those items to be brought before the full, formal Review Board.
August 14	The TPS Formal Review Board reviewed the actions of the screening group, resolved the issues which required their management authority and assigned the actions to be taken in ensuing months.

The distribution of RID's across the TPS technical areas is indicative of where the remaining challenges were found:

Structures (reuseable Carbon-Carbon leading edge, reuse-Surface Insulation-Tiles and Nomex, Thermal Control Subsystem-Internal, Stress/Loads, Materials/Processes)	83
Development Flight Instrumentation and Avionics	14
Aero Sciences	27
Systems Integration	1
Test Program	22
Reliability/Safety	2
Quality Assurance	4
Manufacturing	4

The risk management system for the Orbiter TPS was also reviewed.

The system is continuing to produce hazard assessments. For example, the NASA document "Space Shuttle Safety Concerns Summary Report," JSC 09990, dated December 15, 1975 covers the following:

a. Damage to the Orbiter TPS from the ice shed from the External Tank.

b. Possible impact of the External Tank and Orbiter after initial separation.

c. Damage to the Orbiter by the motor plume from Solid Rocket Booster after separation.

Based on the material presented to the Panel and the discussions between Panel members and NASA and contractor personnel it appears that the review system as applied to the Orbiter TPS is working reasonably well at all levels.

4.2.3 Documentation

The Panel selectively reviews TPS related documents covering the various aspects of the design, test, and fabrication of the Orbiter TPS. Table 4-2 is a partial listing of the documentation reviewed by the Panel since its last report to the Administrator.

4.2.4 Design Progress

Since the basic Orbiter TPS has been described in both prior Panel documents and many NASA and contractor program documents, it

is assumed that the reader is acquainted with the TPS subsyste or has access to the material noted above. Observations as presented here cover several areas: (a) significant changes to data reported in the Panel's last Annual Report to the Administrator, (b) new information developed during Panel reviews and task team activities, and (c) observations of other Panel Task Teams that relate to the developing basis of confidence in the Orbiter TPS' ability to support a successful Orbital mission.

4.2.4.1 Mass Properties

The new Felt Reuseable Surface Insulation (FRSI) replaces a portion of the low temperature tiles (LRSI). This change reduces the TPS accountable weight by some 300 pounds. A description of this newest addition to the TPS is provided in Paragraph 4.2.4.3. However, there are a number of items that are expected to lead to weight increases. These items include definition of the penetrations and closeout, beef-up of the reinforced carbon-carbon panel, the outer moldline fairing, the high pressure gradient flow barrier, the aero-surface seal requirements, LRSI coating thickness and optical property change.

4.2.4.2 TPS Material Distribution

The distribution and configuration of the five (5) different types of TPS materials used to cover the Orbiter surface are as

shown in Figure 4-1.

4.2.4.3 Felt Reuseable Surface Insulation (FRSI)

Studies conducted in the last months of 1974 showed that the minimum gage LRSI tiles overprotected the structure in many areas. The temperature of the structure in these areas was below 350° F. so that it might be possible to have a "bare top surface." This was, however, considered an unacceptable risk for the first orbital flight. The concentrated test and analysis program covered many materials and material systems and finally selected the Nomex felt. Therefore, the LRSI tiles covering areas with surface temperatures of $\leq$ 700° F during entry and at 750°F or less during ascent have been replaced with DC92-007 silicon paint coating on Nomex felt. There is a continuing effort to extend the use of this coated Nomex material to further reduce weight and complexity of the TPS. The only major concern in changing from tile to Nomex was that there might be a "flutter" interaction. Therefore, a two-foot by four-foot specimen is presently being tested at the Ames Research Center to determine the "flutter" characteristics of this assembly. Table 4-4 describes the FRSI material.

4.2.4.4 Orbiter 101

There is a concern regarding the simulated tiles on the Orbiter 101 for the Approach and Landing Test program vehicle. These are

made of polyurethane foam covered with Hypalon coating. The concern is with the foam material and its compatibility with various Orbiter fluids, e.g., hydraulic fluid, APU propellants, etc. There is a potential fire hazard due to this incompatibility. NASA and the Orbiter contractor are examining this area and expect to have a resolution available shortly.

4.2.4.5 TPS Issues

At the time of the Panel's review the following technical challenges were being worked so each is discussed in the following paragraphs:

a. HRSI and LRSI tile coatings.

b. Unique shaped tile

c. Tile-to-tile steps

d. Airframe panel buckling

e. Static door thermal barriers

f. High pressure gradient barriers

g. Use of densified fused silica

h. Use of minimum thickness LRSI tile

i. Body flap, rudder speed brake, elevon aerothermal seals

4.2.4.5.1 Tile Coatings and Unique Shaped Tiles

There is an intensive and detailed materials development program

for the tile coating. The program has been conducted by NASA at the Ames Research Center, Johnson Space Center, Rockwell International, and the Lockheed Missile and Space Company. In trying to meet the RSI tile coating goals, the program has been having problems with cracks in the coating on the sidewalls of the High Temperature Re-useable Surface Insulation. The Low Temperature tiles (LRSI) coating is still undergoing demonstration tests on the mechanical adequacy and characterization of its material properties.

The goals for the RSI coating are to:

a. Minimize devitrification during thermal exposure.

b. Minimize thermal expansion coefficient (about 3×10^{-7} in./in./^{o}F).

c. Minimize morphological (form and structure) changes during thermal exposure.

d. Maintain imperviousness to water.

e. Optimize optical properties; $\varepsilon \geq 0.8$, HRSI $\frac{\alpha}{\varepsilon} \leq 1.0$, LRSI $\frac{\alpha}{\varepsilon} \leq 0.4$

f. Meet dimensional tolerance requirements.

g. Provide as much as possible resistance to ground handling and impact damage.

Based on the latest information available to the Panel the program has an approach to resolving the tile coating problem. The present coating (identified as #0050) consists of silicon carbide and

cobalt oxide emissivity agents. The basecoat is slip cast fused silica with a basic borosilicate glass as the coating. The test program to resolve the #0050 coating problems involves Lockheed, Rockwell, Ames and JSC support during the first portion of 1976. At the same time there is a program to evaluate the reaction cured glass coating process developed by Ames Research Center. The so-called reaction cured glass coatings are produced by blending the components, then affixing them by spray or paint on the substrate and finally heating the coated tile rapidly to the reaction temperature for the reciprocal action of the ingredients on each other. The result is a three-layered coating with an outer layer of Boron Oxide rich glass, a center layer of Borosilicate glass + Tetraboron Silicide, and an inner layer against the tile of borosilicate glass. When the tests and analyses are completed it is expected that a final decision on the coating material will be made in mid-1976.

In addition to the effort to produce un-flawed coatings, Rockwell International is evaluating the impact of flaws on mission performance. This seems worthwhile since the coating cracking problem appears to be applicable to the LRSI as well as the HRSI; the tiles are subject to damage by any impact, human or natural; and there is presently no viable test method of detecting the sidewall flaws.

For the total TPS tile program, NASA approved material character-

ization plan specifies that:

"The mechanical properties, as described under test programs are divided into three catagories to prevent unnecessary and redundant testing.

Category 1: The approach is to test enough specimens in one or more critical properties to verify gaussian distribution in a population of specimens taken from multiple batches of material that has not been well characterized previously. Where similar materials have been well characterized or where generous margins are predicted, fewer test specimens are required. A demonstration of a 1.5 safety margin, using material properties degraded by 100 mission thermal history, will satisfy any requirements for further testing of that property.

Category 2: With only a minimum number of data points scheduled in Category 1, some unsatisfactory margins may result. In these cases, Category 1 results will be assessed, and additional testing will be performed. In addition, certain tests will be conducted when information is required but does not result in a design allowable. Category 2 tests cannot be completely de-

fined until Category 1 testing is complete.

Category 3: After satisfactory allowables are generated, other conditions that could affect the useful life of the TPS will be evaluated. These are not yet completely defined but include evaluation of the effect of natural environments, working fluids, temperature overshoot, permeability, and waterproofness."

Only Category 1 tests are defined in the current issue of the test document RI SD74-SH-0156.

4.2.4.5.2 Tile-To-Tile Steps

To assure an undisturbed airflow over the Orbiter tile surfaces the program must assure that the height of adjacent tiles be held within very tight limits. Figure 4-2 shows the 10-mil "forward step" criteria which is an installation problem covering about 17% of the TPS area. Other areas may permit a somewhat greater step difference as shown, i.e., 30-mil forward and 50-mil backward steps in non-critical aerothermo-dynamic areas.

4.2.4.5.3 Airframe Panel Buckling

The problem with possible cracking of thin tiles as a result of structural deflections was noted in the Panel's last annual report. Currently this could be a problem in some 1800 square feet of surface compared to an original estimate of a little more

200 square feet. Therefore, it is an issue which continues to receive attention. The program is considering such proposed solutions as use of softer strain isolator pad (SIP), smaller tiles, strengthening of the structure, and the reduction in thin tile area by using Nomex (FRSI). Trade-off studies indicate at this time that the most cost-effective solution is to revise the structure rather than modify the TPS with the exception of using FRSI.

4.2.4.5.4 High Pressure Gradient Barriers

There are a number of locations, comprising fairly large surface areas, where there are high to low pressure gradients along the tile gaps resulting in increased gap heating and possibly flow-tripping. Such regions where such connections between high and low pressure flow can exist include chines and trailing edges in particular. The problem is to preclude the flow of gas through the gaps with barriers of some type. The manner in which these flow stoppers could be manufactured and installed are still under study.

4.2.4.5.5. Use of Minimum Thickness RSI Tile

This area of concern has been discussed in the previous sections on the possibility of replacing very thin tiles with Nomex Felt; the effect of flutter and structural deflections; and hot gas flow due to high pressure gradients. Thin tiles have a thickness not exceeding

about 0.3 inch. They cover some 2000 to 3000 square feet of Orbiter surface and are susceptible to breakage during handling and launch preparations. Their distribution is as follows:

Straight flat tiles	1000 ft^2 (approx.)
Single curvature tiles	500 ft^2 (approx.)
Double curvature tiles	1000 ft^2 (approx.)

The straight flat tile obviously represent the least problem and can most likely be accommodated by simple methods. However, the single curvature tiles have not demonstrated that they have sufficient strength to be handled in a manner like the flat tiles. Even less is known about the handling qualities and requirements for the double curvature tiles. In any case, it is necessary to demonstrate the techniques that can adequately handle these tiles without undue damage.

4.2.4.5.6 Use of Densified RSI and Thermal Barriers for Doors

Densified RSI is a silicon carbide impregnated RSI for use in those areas where improved dimensional stability and high temperature service are necessary. Applications of this material is currently found in localized areas where static seals are required, around the landing gear doors, the elevon and aft Orbiter/ET umbilical doors. The definition of environmental and dimensional requirements are still in the process of being refined.

The thermal barrier designs for the Orbiter doors and other

critical areas have been completed and will be examined analytically to see what testing should be done to prove the adequacy of the design. One area of continued concern is the surface smoothness requirements over doors and other areas using seals and thermal barriers. If the current smoothness requirements were to be relaxed it could very well result in flow transition from laminar to turbulent at an earlier time in the mission that is used in the design and sizing of the TPS. For example, if the requirements on the nose landing gear door area were changed resulting in an early tripping to turbulent flow, the TPS weight might well have to be increased as much as 2900 pounds to handle the situation.

4.2.4.5.7 Leading Edge Structure

The leading edge thermal protection design uses an all-carbon system protected against oxidation by a coating of reinforced carbon-carbon (RCC). The general design and installation is shown in Figure 4-2. The RCC system covers about 410 ft^2 of leading edge surface on the Orbiter fuselage, wings and empennage. The 3,020 pounds associated with this system is made up of some 1600 pounds of the RCC panels themselves and about 1420 pounds of installation hardware and internal insulation in these areas. The material is subjected to temperatures ranging from about 2300° F. to more than 2600° F. This material will be applied to two specific areas on the Orbiter 101

and extensively used on the Orbiter 102 for its Orbital flights.

The on-going studies assess the capability of the leading edge structural subsystem to withstand cyclic aerodynamic and aerothermal stresses (fatigue properties). This work will be reported upon during the Orbier 102 Design Review scheduled for the April/May 1976 time period. There are the number of Review Item Dispositions (RIDSs) remaining open from prior reviews that can be expected at this stage of the development program. All of these items are being worked. A summary of the RID activity through the first of December 1975 is provided in Table 4-3.

The interface between the RCC installation and the adjacent high temperature tiles (HRSI) has been designed with essentially complete layout drawings as well as completed stress and thermal analyses. Significant areas include the RCC attachments themselves and the thermal barriers internal to the protected surface. Thermal barriers are to be included in the development test program currently underway, i.e., "Wing Leading Edge System" and "RCC/RSI Interface - Nose Cap" tests. Additional updates are expected in the coming months to the analyses used in the current design work.

It has been noted that the Inconel 718 metal in the fittings used to attach the LESS is very susceptable to cracking where small flaws existed and there is an air environment of 1000° F. or more.

This concern was discussed in some detail in the Spring of 1975 by both Rockwell and JSC. It was noted that on all released detail drawings that a reasonable margin of safety has been assured through the use of decreased material values (e.g., tensile strength, etc.) which accommodate possible cracks in the same manner as stress-corrosion is accounted for in the design of such items.

4.2.5 Test Program

The Thermal Protection Subsystem Test Program is extensive. It is being conducted at such locations as:

a. Johnson Space Center - Technical management and development activities.

b. Ames Research Center - Coatings development, material characterization, system development tests.

c. Langley Research Center - Development test activities.

d. Lockheed, Sunnyvale, Ca. - Development of tiles and coating and the production of tiles.

e. Rockwell, Downey, Ca. - Development of total TPS system including the assembly and installation, design and development, maintenance and replacement procedures, etc.

f. Johns-Manville - Basic tile material fibers.

g. Globe-Albany, Maine - Supplier of Nomex felt.

For our purposes this status report focuses on material characterization tests, development tests, and certification tests.

The current test status shows the following position at this time:

a. Material selection tests are approximately 75% complete with final completion scheduled for June 1976.

b. The material characterization test work required for the Orbiter 102 PDR is some 90% complete. This phase of the work is expected to be completed around July 1, 1976. Testing will, of course, be continued as required to meet any changes made to either the requirements or the material used in the TPS.

c. Design development testing will be continuous through at least most of 1977. Verification testing is expected to begin sometime in the last half of 1977.

d. A plan has been developed to assess the inherent capability of the TPS to withstand such natural environments as rain and hail bird strikes. A major objective is the determination of that launch and landing constraints that must be considered in mission planning.

e. The effects of a "lost tile" being examined in detail through testing at the Ames Research Laboratory. The objective of these tests is to determine the survivability of adjacent tile in-

stallations and their resistance to the so-called "zippering" effect because of entry aerothermodynamic forces. This work continues because the earlier test results were not conclusive.

The depth of the test program can be seen from the following examples of work being conducted at the Langley Research Center:

a. Assessment of the leading edge carbon-carbon material to assess mass loss verify the mission life capability of this material and design.

b. Assessment of the nose gear door thermal barrier to evaluate the design concepts for the thermal performance, leakage rates, and reusability.

c. Determination of the thermal response and gas leakage characteristics of the interface between the leading edge high temperature carbon system and the reuseable tile system which adjoins it.

d. Evaluation of the thermal performance of reuseable surface insulation (tiles) to off-nominal high shear environments.

e. Determination of the effects of tolerance buildup on the TPS performance under nominal (turbulent) flow environment.

f. Evaluation of the effects of the sequence and/or combination of mission environments on the TPS tile acoustic fatigue life.

g. Assessment to correlate damaged tile erosion rate with flow shear, and determine influence of damaged tile on primary struc-

ture temperatures during entry.

h. Definition of the design allowables for Orbiter leading edge reinforced carbon-carbon material by determining the synergistic effects of stress, temperature, and pressure on mission life.

At the time of the Orbiter TPS review in August 1975 a number of issues were considered:

a. The methods of dissemination of materials property data by letter followed by revision to the materials handbook was reviewed and is considered acceptable.

b. Materials test plans have been reviewed and the following points made: (1) a plan is required and will be made available for the evaluation of crystobalite formation in fused silica materials (high strength/density) used in high temperature areas of the Orbiter; (2) a plan is being prepared to define the RSI defect and crack acceptance and/or rejection criteria which is necessary for proper Orbiter refurbishment and logistics; and (3) a test plan has been developed to consider the possible effects of launch site environment on the mission life of tiles. This test will be implemented starting in May 1976 and there will be analytical studies conducted concurrently.

c. The planned NASA technology study has been established to continue the investigation of "lost tile" effects. This is mentioned above as a part of the Langley Research Center program in

support of the TPS development and operational understanding work. Previous testing had indicated that tile "zippering" would not occur if a single tile were missing from the TPS pattern. However, there was some question about the effects from the loss of two or more tiles adjacent along the airflow path. Langley tests indicate that if flow reattaches on the bottom of the cavity wall where the tile is missing, unzippering is more likely to occur. This is due to the flow field undercutting downstream tiles and erosion of the underlying Strain Isolator Pad (SIP-Nomex Felt).

d. The scope of the acoustic fatigue testing program has been reevaluated to assure that this program is adequate and timely in supporting design development. This was of particular interest to the designers of the aerothermal seals. There is a feeling that such acoustic fatigue tests should in fact contain a sequence of tests that used combined environments to assure that the seals are adequate to pass certification. This is another of the tests noted under the Langley Research Center support programs.

e. The need for tests of the forward external tank/orbiter attachment region was reviewed. Thermal testing was not considered necessary because: (1) the attach/separation mechanism assembly is replaced after each flight, hence damage to this assembly during entry has no next-flight consequence; (2) analysis indicates the sub-

structure in the attachment region will not be overheated; and (3) the TPS surrounding the penetration is mounted on a removable carrier-plate that can readily be inspected and serviced after each flight.

f. There have been questions regarding the certification plan for the TPS because of the use of prototype pre-production hardware tiles in development test articles that may be used in support of certification and the adequacy of the planned testing procedures, especially in the area of acoustic fatigue. To assure an adequate certification test program it had been decided that prototype hardware may be used and if similarity exists with flight hardware and is approved by NASA. The acoustic fatigue test program will be agreed upon sufficiently in advance of the tests themselves.

4.2.6 Fabrication and Assembly

In its 1975 Annual Report the Panel noted two areas requiring continued attention. The Space Shuttle Program office responded to these questions about design and quality control on the TPS and the procedures, instructions and training requirements for installation of it. (See Attachment 4-1 and 4-2).

The TPS is still in the development stage; therefore, the detailed information regarding the process for installation and verification is also under evolution. Some of the statements provided at the TPS Design Review put this aspect of the program into perspective .

a. Non-standard tile shapes are required to accommodate close-out requirements, tile orientation to reduce gap heating effects and the man penetrations, such as doors, windows, access panels, vents, etc.

b. Tile shape and carrier strip geometry has been standardized wherever possible. Layouts, of course, are in various degrees of completion. Differences in assembly must be ironed-out as the design fully develops.

c. The number of tools or arrays to be used in installing the TPS on the Orbiter is estimated as follows:

Mid-fuselage	88
Wings	50
Vertical Stabilizer	83
Upper Forward Fuselage	44
Lower Forward Fuselage	130
Aft Fuselage, Lower	33
APS Pod	64
RCS Pod, Upper Forward Fuselage	26
TOTAL	517

Such installation arrays are being defined as soon as the engineering layouts become available.

d. The TPS inspection plans (15 May 1975) do not rely on

visual inspection alone as the initial method of damage inspection. Demage, of course, can occur during assembly or as a result of the mission environment. The intent of the visual inspection is to identify both those vehicle areas where there is obvious damage as well as those areas which warrant more detailed assessment because of the external appearance of the tile or similar data. This visual technique is an effective process to identify areas of refurbishment. Detailed discussion of available NDE (Non-Destructive Evaluation) tests and future plans for such are contained in Rockwell International Letter 044-250-75-080, dated 5 August 1975.

e. An example of the attention being focused on the installation problem at this time is the assignment of twelve quality engineers to work directly with the design group during the current phase of the program. NASA has also assigned a quality engineer to monitor the effort on a full-time basis. In addition, a TPS development shop is located adjacent to the design area to assure continuity between the development testing and the design and quality verification efforts.

4.2.7 Logistics and Maintenance

Much of what has been stated above for the fabrication and assembly portion of the TPS program applies to the logistics and maintenance areas as well. These areas are receiving increasing

attention as the design moves forward. For example, Rockwell Internationa is responding to a KSC request for a proposal to develop Space Shuttle thermal protection system refurbishment techniques, which consists of three basic tasks: (1) tile removal and replacement, (2) tile repair, and (3) thermal tile tests at KSC to verify repair methods.

These tasks started in October 1975 and will be completed on or about October 1976.

Handling and packaging specifications and procedures are to be prepared so that the documents covering the TPS handling, storage, transportation, inspection, bonding, machining and coating, and waterproofing will be published and ready in time to support the TPS facilities activation at the Palmdale assembly plant.

TPS tile identification methods are under active consideration with a goal of identifying the tiles with an applicable Rockwell International part number and serial number on the bottom surface of the tile.

4.3 Current Posture

Although basically a new system, the program considers the Orbiter TPS concept appears to be both practical and workable. Design and development testing appears to support this judgment. An example of the maturation of the TPS design is the large reduction in

the number of thin (0.20") tiles resulting from the refinement of entry aerothermal loads and the development of coated Nomex felt for those Orbiter surfaces having expected temperatures below the 650-700° F. range.

Based on the data available to the Panel, the following is the status of TPS development:

a. It is expected that 95% of the layout drawings would be completed by April 1976.

b. The TPS design, fabrication, installation and test activities should meet the Orbiter 102 program milestone requirements.

c. The TPS system design reviews are effective in surfacing those kinds of problems requiring the attention of management and the working levels to assure the TPS meets the requirements on Orbiter 102.

d. The Solid Rocket Booster separation rocket engine plumes do not appear to present an impingement problem.

e. The basic TPS materials have been selected and the "acreage" configuration have been baselined. The interface configuration between the leading edge RCC system and the basic tile system has been finalized.

Specifications and test plans need to be completed as follows:

a. The Lockheed Missile and Space Corporation specification on "heat-up" and "cool-down" rates to assure the tile materials meet

Orbiter requirements requires further definition.

b. The material property data in Rockwell International handbooks used by design and test personnel needs to be updated.

c. The TPS Design Specification, SD72-SH-0101-6, is to be updated and completed on or about July 1, 1976 by Rockwell International.

d. Requirements for acoustic fatigue tests need to be verified.

e. There needs to be a demonstration of a full 100 mission life for the carbon/carbon leading edge material (RCC), especially for that section of the wing leading edge where the shock wave off the Orbiter nose intersects the wing.

f. Aerodynamic heating in the gaps between TPS tiles is a problem where much effort is being expended at this time. This is most severe in those portions of the tile system where a large pressure gradient is present causing increased local flow rates, such as on the wing glove area at high angles of attack.

g. A test and analysis program must be defined to prove that the coated tiles can meet the waterproof requirements necessary for re-use. Coating development activity indicates that this is a difficult area and resolution is expected in mid-1976.

h. The requirements for Development Flight Instrumentation

(DFI) for the TPS are fairly well-defined. The program is in the process of deciding the type and number; the location of sensors in regards to edges, tile gaps, structural members; redundant installations and effects of data point drop-out. The organizational responsibilities for various aspects of DFI must also be defined.

4.4 Addendum

The program has just completed a major baseline review and made number of significant decisions.

4.4.1 Tile Coating

The Ames Research Center "RCG" coating has been selected for the high temperature tiles (HRSI) based on the most recent test results and detailed studies. This black coating should eliminate the coating cracking problem experience during the past months. The original grey-colored coating will be used on the low temperature tiles (LRSI) which has not experienced the cracking problem. The thermal properties (emissivity/absorbtivity) appear to meet requirements.

4.4.1 SSME Heat Shields

The thermal protection system design for SSME base heat shield is shown in Figure 4-3. This shield protects the Orbiter and engine structure from heat transfer during the ascent and entry portions of the mission. It has been estimated that one-half of the shield on a single engine may have to be replaced every four or so flights.

4.4.3 Thermal Seals

The Orbiter body flap and wing/elevon lower cove aerothermal seals require failsafe design. As presently designed these may present a single point failure condition which can be considered a crew

safety hazard. Furthermore these seals as designed are dynamic systems so that safe-life cannot really be proven and inspection for failures is extremely difficult. Although these seal systems include springs, hinges, linkages, rubbing plates they are not subjected to the form of failure mode and effects analyses (FMEA's) used on other mechanisms because they are considred to be structures. The contractor has noted that reliability trade studies have been conducted to support the design and development and the test program.

The test and analysis program for the seals is directed toward demonstrating that:

a. Sufficient structural and performance margins exist so that there is no credible single point failure in the seal system.

b. Sufficient access and ground test provisions have been provided to permit inspection and tests to prove flight readiness.

c. Where structural and performance margins cannot be demonstrated the design shall incorporate sufficient thermal protection to accommodate a safe single entry by means of insulation, heat sinks, etc. To assure hat the current design approach meets the requirements the contractor has been directed to review the following areas and develop a plan and a schedule to (1) determine if the present design can be made failsafe for all flights, (2) reassess maximum gap size allowables, (3) determine if additional test program will increase

confidence, (4) investigate the inspection and maintenance concepts for increasing the ability to meet turnaround times, and (5) Investigate potential modifications to early test missions to enhance the fail-safe concept.

Other areas of thermal seals still being analyzed include the following:

a. The impact of accommodating early boundary layer transition with particular attention given to the forward landing gear door and the external tank/Orbiter/forward attachment points.

b. Use of redundant seal systems based on the results of the activities noted above under the elevon and body flap seals.

c. Payload Bay Door areas.

d. The External Tank Umbilical Door seal.

e. Mechanical properties of thermal brush systems used in the seal and barrier systems.

f. Door rigging on those doors that might have significant deflections during the mission.

4.4.4 Thermal Barriers

In addition to the thermal barrier materials used in the seals around doors and the like, there is also a need for thermal barriers or "gap fillers" between tiles and between tiles and adjacent structures such as windows, the elevon trailing edge, the wing glove and chine,

C-2

etc. Results from wind tunnel tests clearly indicate that gap heating is significantly increased when flow is driven by a high pressure gradient. The amount of heating increase is dependent upon the magnitude of the gradient. For example, a gap temperature of 1490° F. is experienced at a surface temperature of 1400° F. while a gap temperature of some 2000° F. resulted at a surface temperature of 1600° F. General areas of the TPS where pressure gradients exist and where gap fillers are required have been identified.

Concepts devised to meet this problem include:

a. Thermal brush bonded to tile sides.

b. Glass fabric shapes bonded to tile sides.

c. Saffil fibers encapsulated in Irish Refrasil material and bonded to the filler bar currently in use.

d. Saffil fibers plus a knitted wire mesh spring encapsulated in a high temperature fabric (AB 312) and bonded to the filler bar.

Since the bonding of the tile and coating has not been satisfactory to date, the program is considering the use of Saffil fibers made into a brush (Saffil = silica fibers) or encapsulated and bonded to the filler bar rather than the tile coating.

These designs are being tested both thermally and structurally at this time.

4.4.5 Tile Step and Gap Effects

There appears to be a great deal of difficult in maintaining the small/step and gap required between tiles to prevent early boundary layer transition. For instance the nose landing gear door thermal barrier arrangement produces a 0.025-inch step at forward and aft door edges compared with present requirements for not more than 0.017-inch step. The gap between thermal tiles at the same door edges are in excess of the requirement for 0.034-inch width and 0.034-inch depth. Analytical and test work continues in such areas to bring the step and gap problem within allowable bounds.

4.4.6 Structural Thermal Analyses

The approach to the structural thermal analysis is such that it supports the development of structural and TPS designs that are interdependent. The time that it takes to do a complete thermal and stress analysis calculation or iteration on a previous calculation is quite long. These programs are large, complex 3-dimensional mathematical models requiring considerable manpower and computer usage. These programs do not include all three-dimensional effects that influence the structural temperature gradients because Orbiter design schedules preclude that level of detail. Those three-dimensional effects provided as given inputs are parameters that vary longitudinally as well as transversely, e.g., TPS thickness, heat loads, primary structure, and TCS insulation. The Contractor's TPS minimum weight thermal design

and analysis philosophy is to establish RSI thickness requirements and vehicle temperature response based on nominal thermal analyses for aborts as well as normal WTR and ETR missions. All these analyses are planned to be accomplished at a level of detail consistent with Shuttle program funding and schedules. Final vehicle overall thermal and structural capability is to be determined through a progressive flight test program. Predicated on flight test results, design modifications can be effected if required to maintain adequate vehicle operational capability.

The design and quality control for the doors, Thermal Protection System penetrations and thermal seals should be closely monitored by management to assure that the reliability necessary to satisfy safety will be achieved.

Response: The criticality of reliable designs for doors and other penetrations through the TPS and the associated static and dynamic seals is recognized by management. The closing and latching mechanisms for the doors and hatches were identified as SPF's in the FMEA as leading to failure to close and potential category 1 effects. These critical mechanisms and related thermal seals have also been identified in the Orbiter Hazards Analysis. Concern was expressed about the immaturity of design of this part of the thermal protection system during the TPS PDR for vehicle 102 conducted in early August. Schedule milestones have been established for near term adjustments in the design effort to assure satisfactory margins. The Program Director has been apprised of the status and accomplishment of the milestones will be monitored.

It should also be noted that the overall Space Shuttle design has been reviewed with the objective of minimizing the number of TPS penetrations. For example, as a result of a review of doors actuated in flight, the forward RCS installation was modified to eliminate the doors.

The procedures, instructions, and training requirements for installation and quality control of the Thermal Protection System components should be reviewed by program management to assure the aero/thermodynamic requirements are met.

Response: The TPS (Thermal Protection System) is still in the development stage; therefore, the detailed information regarding the process for installation and verification of the TPS is also under development. Significant attention is being focused on this area by both the contractor and NASA. For example, to assure timely and adequate development of quality criteria for the TPS installation and verification process, the contractor has assigned 12 quality engineers to work directly with the design group during the design and development phase of the effort. NASA has assigned a quality engineer to monitor the effort on a full time basis. A TPS development shop is located adjacent to the design area to assure continuity between the development testing and the design and quality verification efforts. NDE (nondestructive evaluation) techniques are currently being developed and tested to assure detection of delamination of tile bonds, material voids, cracks, etc., following installation and flight. Personnel training and certification requirements are being developed concurrent with the installation and inspection processes.

The TPS is an area of great concern to management and it is because of this concern that the action was taken to assign design, quality engineering, and manufacturing personnel to develop the necessary verification processes concurrent with development of the design. Frequent reviews are conducted by both the contractor and NASA management to maintain full visibility of progress and problems encountered in the TPS development.

TABLE 4-1

ORBITER THERMAL PROTECTION SYSTEM ACTIVITIES

DATE	LOCATION	SUBJECT
Feb 1974	JSC	Review of significant shuttle decisions and status
Aug 1974	ARC Lockheed	Test and materials development review and examination of materials characterization/fabrication
Sep 1974	RI	Orbiter TPS
Jan 1975	JSC	Level II (Systems Integration) aspects of TPS
Mar 1975	KSC	Inspection, repair, maintenance aspects of TPS
May 1975	RI	More detailed fact finding associated with TPS testing, installation, maintenance, safety impacts
Jul 1975	JSC	TPS design, installation, tests, safety implications associated with door and vent protection
Aug 1975	RI Palmdale	TPS assembly for Orbiter 101 and 102 Participate in TPS Design Review
Oct 1975	RI	Results of Orbiter 101 CDR and input to 102 PDR
May 1976	JSC	Results of Orbiter 102 PDR relating to TPS

TABLE 4-2

DOCUMENTS ASSOCIATED WITH ORBITER TPS

1. Orbiter Thermal Protection Subsystem (TPS) Design Review Board Minutes. 14 August 1975.

2. TPS Design Review summary briefings, system description briefing, team board briefings, Review Item Disposition Summary, RID and team minutes; all published in RI document SSV75-24-1 dated 14 Aug 75.

3. Typical RI Internal Letters relating to TPS:
   "TPS Evaluation of Updated Design Trajectory Mission 3B" April 30, 1975
   "TPS Evaluation of AOA Trajectory-Nominal WTR" June 16, 1975
   "Thermal Evaluation of OML Faired TPS Thickness for OV 102" July 24, 1975
   "TPS Evaluation of ETR Trajectory With Dispersions" August 1, 1975

4. "Shuttle Orbiter OV-101 CDR Safety Analysis Report Volume I-Management Summary" 15 September 1975, SD75-SH-0135-001.
   "Shuttle Orbiter OV-101 CDR Safety Analysis Report Volume II-Structures" 15 September 1975, SD75-SH-0135-002.
   "Shuttle Systems Safety Analysis Report" June 15, 1975, SD75-SH-0064A
   "Space Shuttle Safety Concerns Summary Report" 5 September 1975.
   "Shuttle Orbiter 102 PDR Safety Analysis Report (Update), SD74-SH-0323, dated July 1, 1975.

TABLE 4-3

Review Item Disposition (RID)

From Previous Reviews

Still Open

LESS/HRSI Gap/Step Tolerance

LESS structural and Dynamic Analysis

LESS/HRSI Internal Insulation

RSI Attachment Around Windows

Thermal Deflection of RCC Expansion Seal

LESS Designs for Baseline Trajectory

(These indicate the areas of some concern from a standpoint of design completion and understanding of the problems involved if not resolved)

Table 6-4

Felt Reuseable Surface Insulation (FRSI)

1. This is Nomex or "E" felt coated with white silicone oxide (DC92-007)

2. The use of this material in lieu of tiles saves about 345 pounds

3. Physical Properties

- Maximum allowable temperature for one mission	900°F
- 100 Mission Life Maximum allowable temperature	700°F
- Density, lbs/ft^2 with thickness of 0.4 inches	0.24
- Coating thickness (DC92-007)	0.0075 inches
- Area covered, ft^2	2800

4. Manufacturing process
   Nomex felt is heat treated to 700°F for 30 minutes, then it is treated at a raised temperature of 750°F for another 30 minutes. This accomplishes the pre-shrinkage step. After application of the coating (DC92-007) there is a post cure for 15 minutes at 650°F.

FIGURE 4-1 ORBITER THERMAL PROTECTION SUBSYSTEM

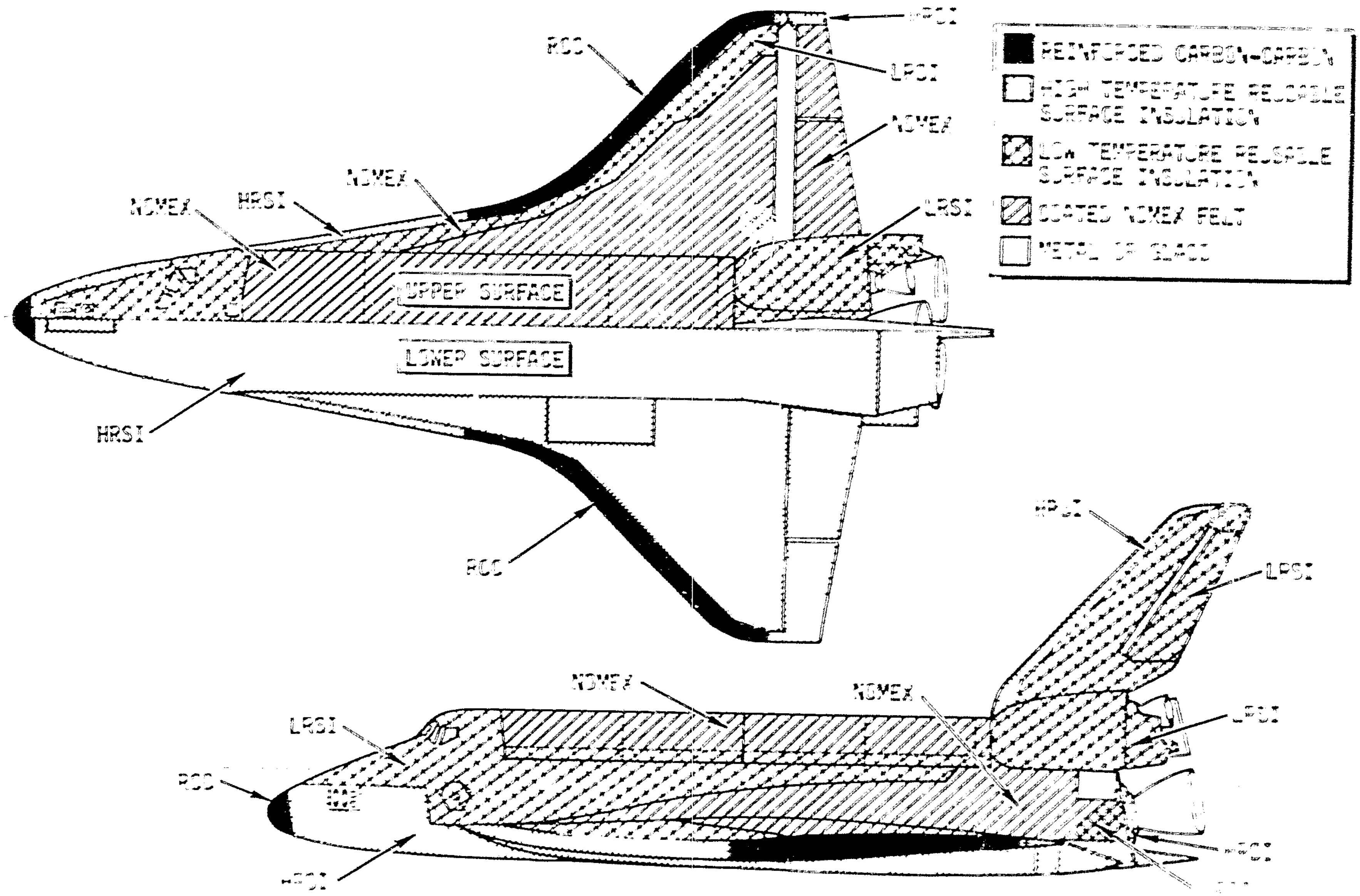


FIGURE 4-2 ORBITER TPS INTERFACES

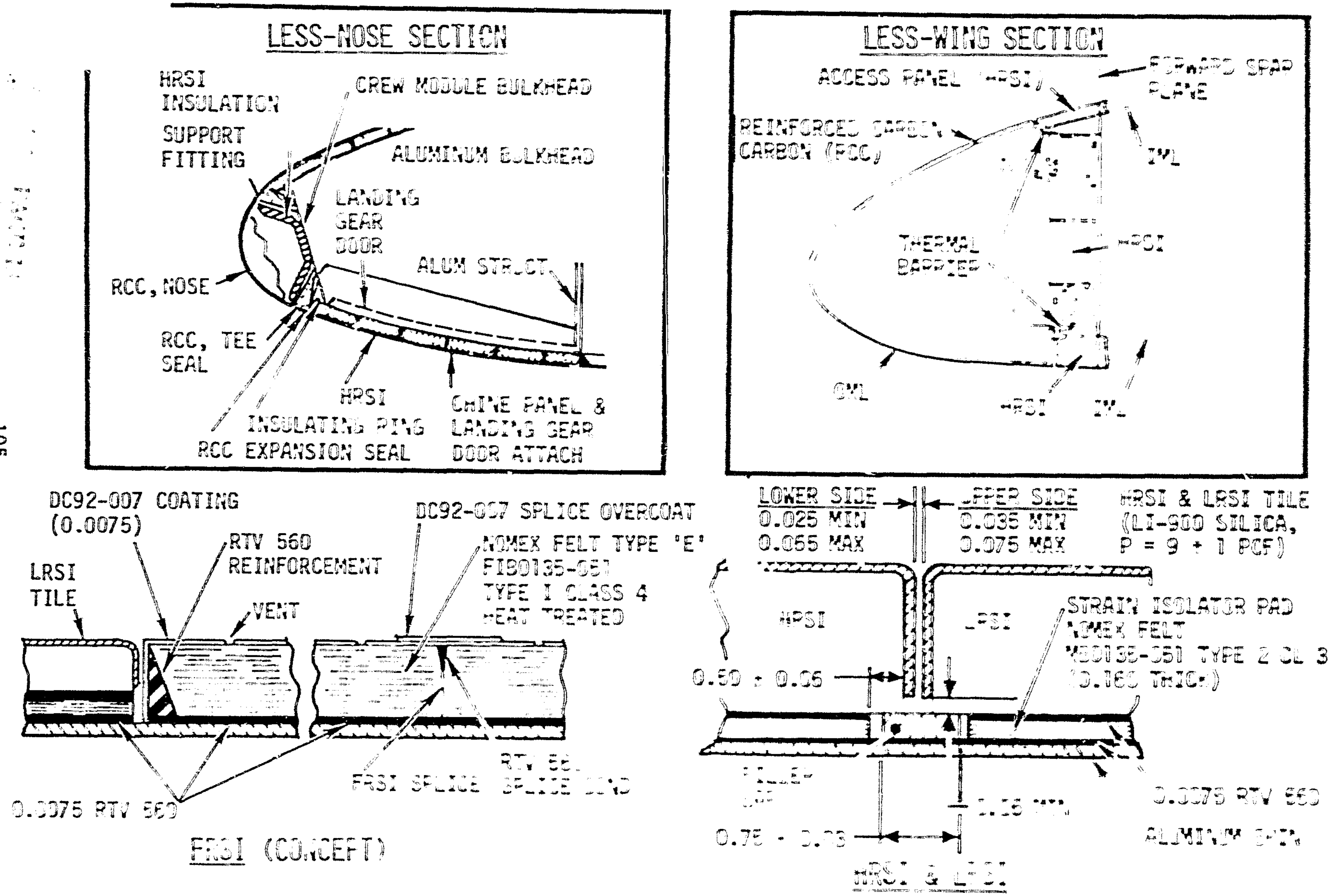
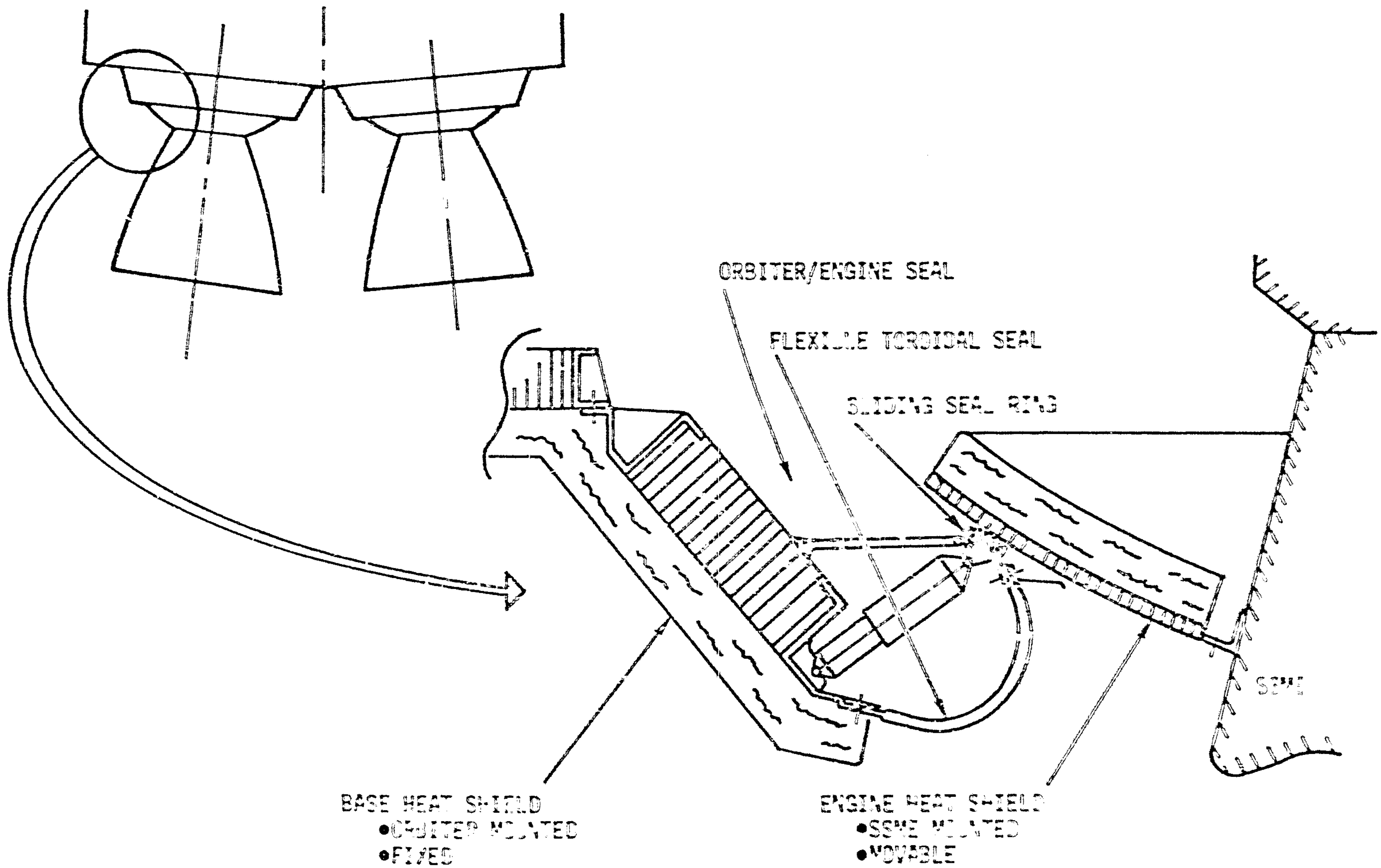


FIGURE 4-3 AFT HEAT SHIELD



5.0 AVIONICS MANAGEMENT

5.1 Introduction

The Shuttle avionics system provides command functions including their implementation, guidance, navigation, and control capability, communication, computation, displays and controls, instrumentation, and electrical power distribution and control for the Orbiter, External Tank, and the Solid Rocket Boosters. There are also provisions for the management and control of payload functions and for the communication of data to and from payloads.

Avionics was placed high on the list of areas to be examined and assessed by the Panel because the fabrication, test, and verification of the integrated system of avionics hardware and software is vital to the success of the current phase of the test program and later mission operations, and it is an area most likely to affect and be effected by resources and schedules.

Attachment 5-1 is the Shuttle Office response to the Panel's concern that the management system for avionic hardware and software should be reviewed by senior program management to assure it is adequate for the indicated complexity of the program.

Shuttle Orbiter avionics for the purposes of this discussion falls into two identifiable areas: (1) the Orbiter 101 avionics used during the verification testing and Approach and Landing Test project, and (2) the Orbiter 102 avionics used during the orbital flight tests

and initial flights following DDT&E. The Orbiter 101 avionics system provides the necessary signal acquisition, handling, processing, display and powering to enable the navigation, control, and information interchange required for the approach and landing test project. Specifically, the avionics system for Orbiter 101 contains:

a. <u>Guidance and Navigation</u>

(1) Three Inertial Measuring Units (IMU).

(2) Navigation Base (NB).

(3) Software in the general purpose computers.

b. <u>Air Data</u>

(1) A sensory system to measure static pressure, total pressure, lower and upper alpha port pressures, and indicated total air temperature.

(2) Air Data Transducer Assemblies to provide digital inputs from the sensing system to the general purpose computers.

(3) Probes that are mechanized for stowage and deployment as required.

(4) Special aerodynamic probe mounted on a boom attached to nose of the Orbiter with a dedicated separate air data computer and panel mounted displays. This separate system is used to calibrate the operational system.

c. <u>Flight Control</u>

(1) Orbiter 101 has a backup flight control system using the independent air data sensors and dedicated general purpose computer as an alternate to the primary flight control function.

(2) Flight control components involved in the avionics-to-actuator interface are:

Rate gyro assembly
Accelerometer assembly
Rotation hand control
Speed brake thrust control
Rudder pedal transducer assembly
Aerosurface servo amplifier
Reaction jet driver forward
Reaction jet/OMS driver
Ascent thrust vector control driver

(3) Flight control digital autopilot software to provide the basic flight control functions.

d. Communications and Tracking

The RF, processing, and distribution equipment necessary to provide the many input, output and process activities.

e. Displays and Controls

(1) Controls

Rotation Hand Controller (this is noted above as well)

Rudder pedal transducer assembly (this is noted above as well)

Speed Brake Controller (this is noted above as well)

Keyboard used to interface with the CRT display and to manage the information displayed. It is also used to provide entry

to send control commands to the computers.

(2) Displays

(a) Attitude Director Indicator (two-axis, roll and pitch).

(b) Surface Position Indicator (for aero-controls)

(c) Alpha/Mach Indicator

(d) Altitude/Vertical Velocity Indicator

(e) Horizontal Situation Indicator

(f) Orbiter Display Unit (CRT flight computer information)

(g) Computer Status Annunciator Assembly

(h) Fire Warning Annunciator Assembly

(i) Caution and Warning Subsystem

g. <u>Instrumentation Subsystem</u>

This consists of sensor transducers, signal conditioning equipment, PCM encoding equipment, frequency multiplex equipment, PCM tape recorders, analog recorders, timing equipment, and on-board checkout equipment.

The system is made up of two separate parts: (1) the operational instrumentation (OI), and (2) development flight instrumentation (DFI).

h. <u>Data Processing and Software</u>

(1) Five general purpose computers (GPC).

(2) Two mass memories - magnetic tape memories for

large volume bulk storage and organizational information.

(3) Eighteen Multiplexer/Demultiplexers (MDM).

(4) Remote interface units to convert and format data at system interface.

(5) Multifunction Cathode Ray Tube (CRT), three of these.

(6) Display System.

(7) Data Bus and associated equipment.

(8) Software for all computers.

i. Electrical Power Distribution and Control

This system provides power distribution and power control for all Shuttle Systems during operational phases. It interfaces with all subsystems that require signal power and operational power.

Following are the changes for the Orbiter 102 operational type vehicles:

a. The Star Tracker and Light Shade Units are added to the Guidance, Navigation and Control system.

b. Removal of air data components used for calibration of the system during Orbiter 101 test phase.

c. Addition of S-band.

d. The Engine Interface Unit used between the Orbiter controls and the SSME will be added to command and status the SSME during

Orbital Flight. A brief overview of the operational system is shown in Figure 5-1, and the Data Processing/Software arrangement is shown in Figure 5-2.

5.2 General Purpose Computer (GPC)

In the Orbiter 101 there are five GPC's in the Orbiter on-board computational complex. Four of the GPC's are synchronized, containing the identical primary program loads. The fifth GPC on the ALT phase of Orbiter 101 is dedicated to support the backup flight control system. This backup flight control system is a primary safety function in this phase of the program.

Each GPC is a modified IBM AP-101 microprogram controlled Central Processing Unit (CPU) with a unique Input/Output Processor interface to the serial data bus network. These two line replaceable units, the CPU and the Input/Output Processor, contain portions of main memory which are used by either the CPU or the Input/Output Processor on a nondedicated basis. The CPU initiates all input/output actions through the execution of instructions to the processor. These instructions and data words are transferred between the CPU and the Processor on a bidirectional, parallel word data bus. Except for initiation, the processor is independent of the CPU and executes its own programs, which reside in the common main memory. Read-only storage is used for controlling a fixed sequence of operations and

internal data paths to be executed for each instruction.

5.3 Performance Monitoring System (PMS)

The PMS on Orbiter 101 is considerably less complex than the one on Orbiter 102 which is used for orbital missions. The Orbiter 101 PMS as used during the ALT project provides for automatic fault detection and annunciation, and subsystem measurement management. Additional PMS functions for Orbiter 102 OFT and operational missions include the following: (1) subsystem configuration management, (2) consumables management, (3) data recording management, (4) telemetry format selection, (5) payload support, (6) mission proper storage and retrieval, (7) performance evaluation and trend analysis, and (8) contingency planning aid. The smaller 101 PMS program is resident in each of the four GPC's used for the primary flight control system.

Automatic fault detection and annunciation detects subsystem failures at the functional path level, which is the level corrective action can be taken in flight. This system is implemented through the avionics software. When the failed parameter is one of the safety critical caution and warning parameter group items a backup caution and warning master alarm signal is generated. A PMS crew alert alarm consisting of a small blue light and a short duration buzzer is initated when any parameter is declared failed. Thus the PMS provides a backup capability for the hardwired Caution and Warning subsystem in alerting the crew to any detected hazardous or potentially hazardous condition which requires attention.

The Subsystem Measurement Management software enables the crew

to call up on the CRT the measurement data so the crew can assess the degree of a problem.

5.5. Orbiter Avionics Installation

The major portion of avionics can be found in the flight deck, the three forward avionics equipment bays, and the three aft avionics equipment bays. All antennas, except those used exclusively for satellite tracking and EVA communication, are flush mounted on the top, bottom, and sides of the Orbiter forward fuselage. These antennas include:

a. Four S-band seven-element antennas for phase modulated (PM) communication with space/ground link system and STDN ground stations and the NASA tracking and data relay satellites.

b. Two S-band FM antennas.

c. Four C-band horns for the radar altimeter.

d. One UHF antenna for EVA/air traffic control voice communications.

e. Six L-band TACAN antennas.

f. Three Ku-band microwave scan beam landing system antennas.

g. One integrated Ku-band communications/rendezvous radar antenna and one Ku-band communication used with the NASA Tracking and Data Relay Satellite.

h. One S-band PM payload antenna.

5.6 Orbiter Radio Frequencies

The Orbiter carries up to 23 antennas for communication with ground stations, detached-payloads and crewmen doing EVA. They use S-, Ku-, L-, C-, and P-band frequencies. Table 5-1 shows the system function and the Orbiter frequency for transmitting and for receiving signals.

The Ku-band links the ground stations and the Orbiter via the Tracking and Data Relay Satellite System. It carries the same kinds of intelligence as the S-band subsystem, but at wider band-widths and higher data rates. The Orbiter rendezvous radar and the Multiple Scan Beam Landing System also works in the Ku-band. The Ku-band systems capabilities and vehicle locations are shown in Figure 5-3.

5.7 Microwave Scanning Beam Landing System (MSBLS)

The MSBLS will provide information to he Orbiter avionics computer during the critical autoland period of flight. The MSBLS is used during the last 75-seconds of Orbiter flight. While the nominal acquisition range is about 12 n. miles, the range in practice depends upon Orbiter flight path, attitude, and weather constraints.

The system consists of the ground station and an airborne navigation set. The ground station is divided into an elevation equipment group, Figure 5-4, and an azimuth/distance measuring group, Figure 5-5. The airborne equipment is divided into a decoder-receiver unit and a DME transmitter unit. Figure 5-6 shows the major

elements and the radio-frequency links which are used in the MSBLS.

5.8 Avionics Laboratories and Test Plan

There are three laboratories of major significance to the avionics test program. In principal the Software Development Laboratory at JSC is for the development and verification of software. The Avionics Development Laboratory at Rockwell International is for the evaluation of avionics hardware/software. The Shuttle Avionics Integration Laboratory at JSC is for the validation of the integrated avionics hardware and software system. In practice the laboratories are also used as needed to work through technical challenges. The following sections describe each of the laboratories and the test program for validation of Orbiter 101 hardware and software for ALT.

5.8.1 Software Development Laboratory (SDL)

This facility at JSC is used for software coding, development testing and for verification of the flight software. It provides the capability for high fidelity execution of flight software, variable fidelity simulations of vehicle and avionic subsystems to provide nominal and off-nominal performance, diagnostic aids to force test conditions and collect/analyze results, and an automated and semi-automated set of techniques to provide rigorous software configuration management. This facility has been operating in support of

the SAIL and Palmdale Plant checkout work.

5.8.2 Avionics Development Laboratory (ADL)

The ADL is an engineering tool with emphasis on avionics hardware development, subsystem evaluation and initial hardware integration. It is set up as shown schematically in Figure 5-7. This facility is located at RI/Space Division, Downey, CA. The major ADL flight control tests cover the test and checkout procedures for the Orbiter 101 at Palmdale; the Backup Flight Control System (BFCS) closed-loop performance; the primary to BFCS switchover; primary flight control system performance testing and actuator tests; and closed-loop testing with the Flight Control Hydraulics Laboratory (FCHL).

The status of work being done at ADL is summarised as:

a. Software evaluation tests are in process on those tapes to be used for test and checkout of Orbiter 101. The programs or tapes to be used include SU-1, SU-1A, VU-101/ADL-3A, FACI, ADL-3B, OPS-9, SU-89, and ADL-3. These tapes will also support the SAIL integration testing.

b. The ADL is using two production general purpose computers (GPC's) to support the dry runs of test and checkout procedures and memory loading tests for GSE support.

c. Both Single-string and Multi-string open and closed-loop engineering studies are being done.

d. Work load at ADL now and in the future will be quite heavy to meet the required evaluations and verifications. With proper scheduling and no major problems this work load should be accommodated.

5.8.3 Shuttle Avionics Integration Laboratory (SAIL)

The SAIL at JSC gives NASA the capability for extensive closed-loop mission evaluation of the avionics system as it will be used in flight. This capability includes testing for specific off-nominal conditions. After outlining the scope of the activities planned for SAIL, the differences between the equipment used in SAIL and the equipment to be flown on Orbiter 101 are discussed to provide an understanding of the capability of the SAIL to support Orbiter development and flight programs.

5.8.3.1 Test Activities

To give an idea of the scope of the total SAIL test activities, a brief definition of the four test phases is as follows:

PHASE I TESTS - Activation and establishment of the operational capability of the SAIL checkout should be completed by July/August 1976 time-frame. A prototype/breadboard version of the avionics test hardware will be used.

PHASE II TESTS - Orbiter avionics software systems performance in support of the ALT program requirements will be verified during this phase. Priority has been placed on verifying the Backup Flight Control software and then utilizing this configuration to buildup and integrate flight systems. It is expected that the Software Development Laboratory (SDL) software will be utilized for the buildup of those flight systems not covered by the BFCS. The final

flight system buildup, integration, and laboratory verification will be accomplished with those software tapes or programs designated as VU-101 CI, ADL-5/MS FACI, and OPS-01 Pre-release. This software is used in order to have SAIL ready to support closed loop testing in September/October 1976 period.

PHASE III TESTS - Testing will be conducted to support the orbital flight missions.

PHASE IV TESTS - Testing will support the Shuttle avionics operational requirements. Thus there will be update of SAIL to the required hardware/software configuration.

5.8.3.2 SAIL Equipment

5.8.3.2.1 Simulated Surface Actuators

A special purpose electronic simulator has been designed and is being built in-house at JSC to appear functionally equivalent to the real hardware and interface directly with the hardware aerosurface actuators. To assure the simulation is adequate, the system functions will be compared with those from hardware at the flight control hydraulic laboratory and from the Orbiter 101 vehicle. This comparison will cover (1) position gain and phase shift versus frequency, (2) secondary pressure monitoring, and (3) vehicle/flight control system closed-loop structural mode stability.

5.8.3.2.2 Functionally Equivalent Prototype vs Qualifiable Equipment

Where prototype equipment is used it is planned to recycle them after they have been modified and updated to maintain functional equivalency with flight-type hardware.

5.8.3.2.3 Development Flight Instrumentation Not In SAIL

Omissions are in the sensors and harness normally connected to the operational instrumentation multiplexers/demultiplexers. These do not affect the flight control system or the data processing system.

5.8.3.2.4 Use Of Special IMU Mount

Since SAIL does not test the structural dynamic environmental effects on sensors but does simulate structural dynamic coupling into the flight control sensor signals the Navigation Base is simulated with a special mounting provision for the IMU. The Navigation Base provides a rigid mounting for the three IMU's and the two Star Trackers, included in the Orbiter 102-and-on vehicles, whereby precision alignment of these critical navigation devices may be maintained throughout Orbital flight.

5.8.3.2.5 Backup Flight Control System (BFCS)

The G-meter and attitude indicator are simulated and it is not a SAIL objective to test this equipment. The SAIL, however, does need these functions represented in the system for the necessary system level functional evaluations.

5.8.3.2.6 Flight Harness

There are a number of differences between flight and SAIL electrical cabling or harnesses. These involve interfaces with simulated

non-avionics equipment and DFI ommissions since EMI testing is not a SAIL objective. While SAIL uses single point ground due to lack of vehicle structure, the flight hardware uses the vehicle structure as ground. The interfaces with the dynamic motion simulator require non-standard harness to mount the IMU and other equipment.

5.8.4 The Test Program for OV-101 and ALT

The avionics verification program is now taking shape. The concept for the Approach and Landing Test Project (Orbiter 101) is shown schematically in Figure 5-8. The relative working relationships between the SAIL, ADL, etc. are readily seen here. Additional information concerning the SAIL system tests can be found in the following documents:

a. SD75-SH-0079 "Integration and Preflight Tests" (System Integration).

b. SD75-SH-0080 "Preflight, Taxi, Take-off, and Climb" (ALT Captive Tests).

c. SD75-SH-0081 "Cruise Mission Phase" (ALT).

d. SD75-SH-0082 "Separation Sequence/Mated Flight (ALT).

e. SD75-SH-0083 "Descent, Landing, and Post-Flight Taxi-Mated Flight Phase".

The factory checkout and integrated test programs at Palmdale for Orbiter 101 is scheduled between March and November 1976. It has

the following objectives:

a. Verify manufacturing assembly operations by demonstrating Orbiter subsystem performance to engineering design requirements and subsystem and combined subsystem functional paths.

b. Demonstrate functional integrity of all systems when operated in various flight modes and selected backup, redundant, and abort modes as well as verifying intra-systems compatibility and electromagnetic compatability of subsystems.

5.9 Other Test Capabilities to Support Avionics Activities

5.9.1 Electronic Systems Test Laboratory (ESTL)

This facility at JSC is to be used for development tests, end-to-end compatibility tests, and performance verification of the Shuttle space communications and tracking system. It is to have an interface with SAIL by both RF and hardware. Support of the program is expected to begin with the orbital flight test phase.

5.9.2 Training Simulator Projects

Major items comprising the training simulator projects include the following:

a. Shuttle Mission Simulator - deliveries scheduled for Spring and Summer of 1978.

b. Shuttle Mission Simulator Computer Complex - delivery

of the hardware/software is expected in Summer of 1976.

c. Orbiter Aeroflight Simulator - delivery is expected in September 1976.

d. Shuttle Procedures Simulator - it is an in-house development at JSC and currently in use there.

e. Crew Procedures Evaluator Simulator - it is also an in-house development at JSC and is in use there.

f. The Shuttle Training Aircraft (STA) - two aircraft have been built to simulate the flying qualities and trajectories of the Shuttle Orbiter. These aircraft are to be used to train the Shuttle pilots by duplicating, in so far as practical, the handling characteristics and visual cues expected to be experienced in flying the Shuttle Orbiter in the Terminal Area Landing Trajectory.

The management systems for the simulation activities emanates from the Operations Integration Office at Level II at JSC. The management scheme is shown in Figure 5-9. In addition there is a Space Shuttle Program Simulation Planning Panel established by Program Directive 1A, dated May 21, 1974 which is to provide the mechanism for accomplishing coordination, planning, and review of simulation activities.

5.10 Avionics Management

The Panel in examining this broad area spent some time in understanding the hardware, software, facilities and test programs asso-

ciated with the avionics program. The Panel reviewed the organizations in existence which manages the avionics work: (1) Orbiter avionics systems office at Project Level III, (2) Technical Assistant and his division covering avionics in the engineering directorate, (3) data systems and analysis directorate, (4) integration and check-and-balance functions including the integration office at the program level; such technical panels as the Integrated Avionics Steering Group, the SIR and CSIR and associated Panels; hardware and software configuration/change control boards; and the technical review process including system design reviews on each mission phase. The following sections indicate some of management's actions to assure effective management of avionics development.

5.10.1 The Program Management Panel System for Avionics

Based on the Program Directive setting up the Space Shuttle Integrated Avionics Technical Management Area, the following responsibilities are given to the Systems Engineering Office at Level II:

a. Assessment of the technical adequacy of the overall performance of avionics systems for the Space Shuttle vehicle within the available resources.

b. Coordination, publication, and implementation of a plan, including task definitions and schedules, for the accomplishment of the technical manager's responsibilities including establishment of

the membership of the integrated avionics panels.

c. Management of the activities of the integrated avionics panels to assure adequate communications and understanding between all personnel involved as well as program management. Membership on the Systems Integration Review (SIR) panel which supports integration activities across the program.

Four panels and a steering group were established as follows:

a. The Integrated Avionics Steering Group which brings together avionics management personnel from JSC, MSFC, KSC, and Rockwell Space Division.

b. The Shuttle Avionics Panel which serves as a technical planning, reviewing, and integration team for all Shuttle avionics interfaces. Their work includes conceptual studies, system analysis and syntheses, trade studies, preliminary design, and supporting technology essential for the specification of the functional and performance requirements of the integrated avionics systems.

c. The Flight Communications Panel which insures the compatibility, performance, and timely definition of communications and tracking system interfaces and identifies problems, determines corrective action, and recommends appropriate action to the technical manager.

d. The Shuttle Avionics Checkout Panel which serves as a

forum for the integration of the avionics checkout and prelaunch testing requirements for the elements of the Shuttle system. Their work covers review of requirements, test procedures, avionics test software requirements, and the resolution of avionics checkout issues for factory checkout at Palmdale, ALT pre- and post-flight checkout, checkout and maintenance testing at KSC, and support of pre- and post-flight checkout for the operational phase of the program.

e. The Shuttle Avionics Verification Panel which serves as a special working group for planning and coordinating the test activities of JSC, KSC, MSFC, and Rockwell.

5.10.2 Special Requirements Reviews

Management has focused a great deal of attention on the hardware-to-software compatibility aspects of the avionics systems at every level of the program and at every major step in the schedule. For instance there have been a number of special reviews of software requirements for the ALT and the OFT phases of the Shuttle program. These have been termed "scrub" activities and they are planned as a continuing activities to assure requirements are well defined and can be met. The methodology used in these activities generally follows these lines:

a. Review the approach and the results of previous scrub activities along with the most current hardware configurations and

performance requirements.

b. Establish the goals and basic capability requirements to be used as decision criteria.

c. Conduct reviews with pertinent managers and key technical personnel to assure a common understanding of the scrub groundrules and expectations, assess software module functional content requirements and agree on possible deletiors with their impact.

d. Finalize the specific requirements modifications, deletion and additions as options to be proposed to management. Particular attention is given to assure they have not reduced the capability to protect against software generic failures and the like.

e. Present the options to management for their decision along with the backup material upon which decisions can be made.

5.10.3 Program Activities

In response to the Panel's reviews of avionics hardware/software the following areas are receiving special management attention:

a. Management is sensitive to the fact that establishing minimum levels of testing on which to base a flight worthiness decision is a difficult judgment. The avionics system, of course, must work because it is not tolerant of generic failures in the software.

b. Management has established teams to review the requirements and assess the impact of any changes suggested. The team approach is equivalent in purpose to the System Design Requirements Reviews. A team has JSC, Rockwell Internation Space Division and IBM members. The membership reflects the projects new approach on integrating Rockwell and IBM operations more closely on a day-to-day basis so potential problems can be worked out early.

c. The IBM schedule is tight and initial verification requirements are being reassessed. However, management is looking to the SAIL test programs to provide a more comprehensive validation of the software as a supplement to the IBM efforts.

d. Management is carefully controlling new requirements after the software requirements are authorized at the System Design Requirements Reviews. Currently only mandatory changes are approved.

e. Because of recent scrubs the software requirements for ALT are currently within the capacity of the memory.

f. The verification schedule for ALT is tight. The Level I milestone of completing the ALT flight software verification has been changed from July 1976 to November 1976. Management is now planning its response to this situation.

g. Plans are being made to validate late modifications to the software in the SAIL facility, but if these mods are much greater than planned for, there will be a schedule problem at that time.

5.11 ADDENDUM

5.11.1 ALT Project

The computer program end items (CPEI's) provide the capability for checkout of the Orbiter avionics subsystems at the factory perform the required preflight and flight operations. The basic programs associated with ALT and the Orbiter 101 of direct interest to the Panel are:

a. OPS 8 and OPS 9 - Systems Management

b. OPS 1 - Preflight Checkout

c. OPS 2 - Flight Operations

The requirements for OPS 1 and OPS 2 have been scrubbed to bring them well within the storage capability and processing rates (time to process) of the general purpose computer. The results of the latest scrub actions and an idea of available margins is shown below:

ALT (Orbiter 101)	OPS 1		OPS 2	
Before scrub	64,060 wds	107.0% rate	67,270 wds	91.7% rate
After scrub	52,880 wds	57.2% rate	54,190 wds	66.4% rate

Current schedules have the software programs for tailcone off ALT operations to be completed first although such flights come last. Then

through parameter changes the ALT tailcone on software programs will be completed. This, however, necessitates the verification and final checkout of the "ON" software to be accomplished late in the program at DFRC, very close to flight time.

5.11.2 OFT Project

The software program requirements for the ascent and entry phases have been scrubbed with the following results:

OFT (Orbiter 102)	Ascent Software	Entry Software
Estimated Current Size	56,900 words	52,400 words
Estimated Additional words to be added as known today	700-800	500-600

Program management is using the lessons learned in developing the ALT software to enhance the OFT software development program. As a result a more detailed OFT work plan to assure adequate and timely daily direction, visibility and control is being established. For example "Mode Teams" have been established to define, integrate and simplify software requirements and to work problems as they arise. Sixteen such teams have been or will be established to cover every major aspect of the mission phases. The first meetings of some of these teams was conducted during the last week of May 1976 at the RI/Space Division.

5.11.3 Further Actions

Program management has also instituted weekly telecons between

JSC, RI/Downey, RI/Palmdale to review status and progress on the avionics checkout being conducted on Orbiter 101.

A permanent scrub group is to be formed soon to assure that all requirements laid on avionics software and hardware will be compatible and that there will be sufficient margins to accommodate the growth in requirements as the OFT mission matures.

The management system for avionic hardware and software should be reviewed by senior program management to assure it is adequate for the indicated complexity of the program.

Response: The avionics management and development plan is considered a critical element of the Space Shuttle Program. In January of this year the avionics and flight control status was reviewed at the program director and Director of MSF levels. The areas of coordination of the hardware/software technical work and the degree of the contractor responsibility were identified, among others, as requiring further management attention. The Rockwell responsibility in avionics has been clarified and strengthened by emphasizing their areas of responsibility and objectives. Specific adjustments have been made. As an example, they have been requested to include the overall computer memory and operations duty cycle estimates and requiring them to establish bogies for each of the program elements of the software resident in the onboard computer. They have been required to prepare a cost effective overall avionics development plan utilizing engineering simulations at RI and NASA ADL, SDL, and SAIL facilities to support 101 and 102 schedules.

A review of the total flight control area was conducted and a single individual was identified as having total flight control responsibility for both Level II and Level III for the Space Shuttle Program. He prepared a total review of the status of flight control design, requirements, management, and required resources, together with a flight control development plan. This review and plan were presented to the center director who approved the plan in June of this year.

The Space Shuttle Orbiter Project Office avionics effort has been strengthened by clarifying responsibilities and by adding personnel. A weekly avionics system review working meeting has been established with the RI Associate Engineering Director of Avionics, the software contract manager, the NASA avionics systems engineering manager, and chaired by the Space Shuttle Project Office avionics manager. The avionics manager reviewed the center plans for integrating the avionics effort with the Space Shuttle Program Director and the Associate Administrator for Space Flight in June.

A single individual has been identified and established by appropriate directives as the focal point for all Space Shuttle avionics engineering. At this point, Level III and Level II hardware and software responsibilities are combined. The chief of avionics engineering and the Space Shuttle Project avionics manager are preparing an overall avionics development plan and a management plan to be presented to the Space Shuttle Program Director and the Associate Administrator for Space Flight on September 29.

TABLE 5-1

ORBITER RADIO FREQUENCIES

FUNCTION/SYSTEM	ORBITER TRANSMIT	ORBITER RECEIVE
STDN PM-1	2287.5 MHz	2106.4 MHz
STDN PM-2	2217.5 MHz	2041.9 MHz
STDN FM	2250.0 MHz	NONE
DFI FM	2205.0 MHz	NONE
NASA PAYLOADS	2025.0 TO 2120.0 MHz	2202.5 TO 2297.7 MHz
EVA COMMUNICATIONS	296.8 MHz	259.7 MHz
RENDEZVOUS (RADAR)	Ku-BAND	Ku-BAND
Ku-BAND COMM	Ku-BAND	Ku-BAND
RADAR ALTIMETERS	4.3 GHz BAND	4.3 GHz BAND
TACAN	1025 TO 1150 MHz	962 TO 1213 MHz
ATC VOICE	225 TO 400 MHz	225 TO 400 MHz
MSBLS	Ku-BAND	Ku-BAND
ATC TRANSPONDER (FERRY KIT)	1090 MHz	1030 MHz

FIGURE 5-1

SHUTTLE AVIONICS SYSTEM

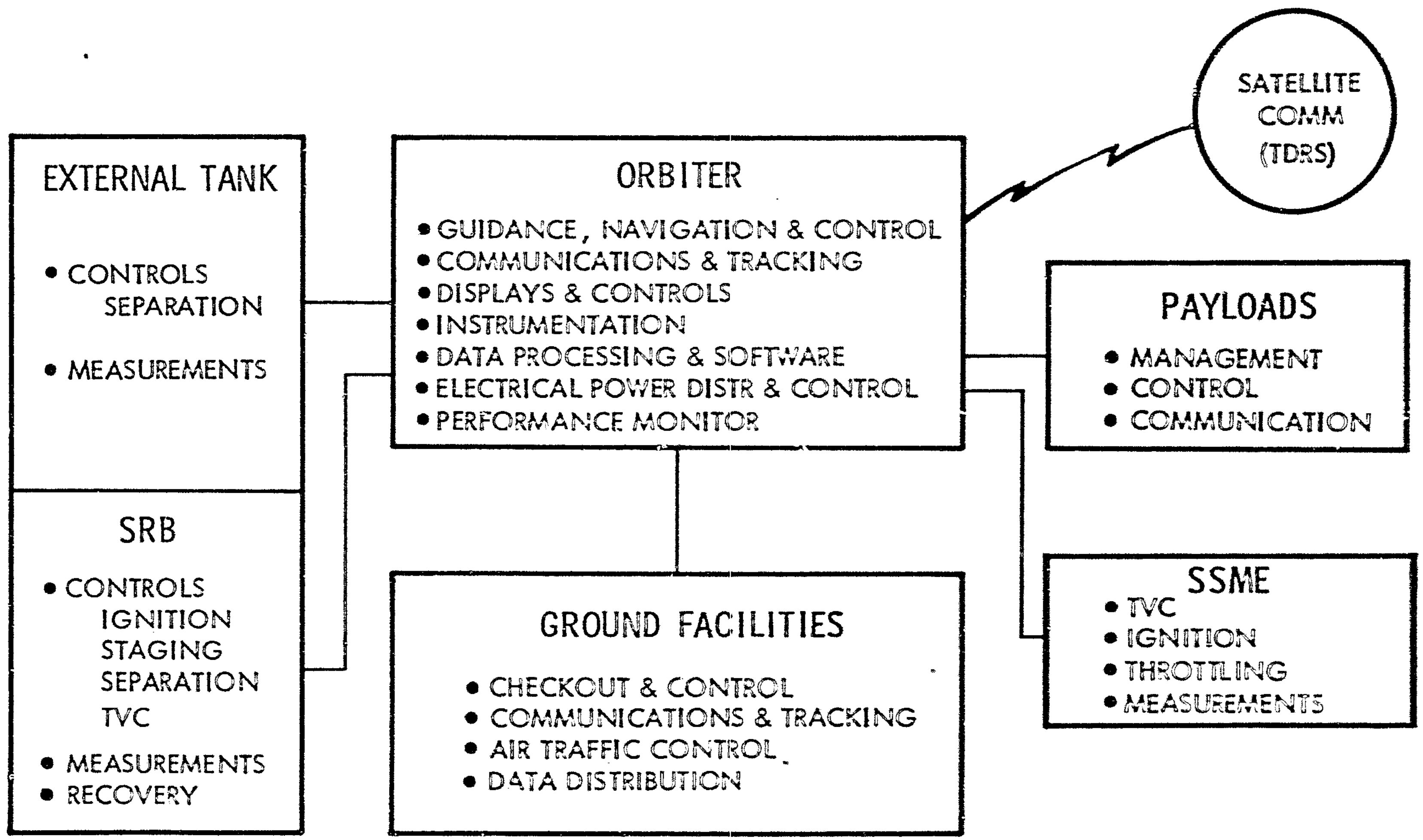
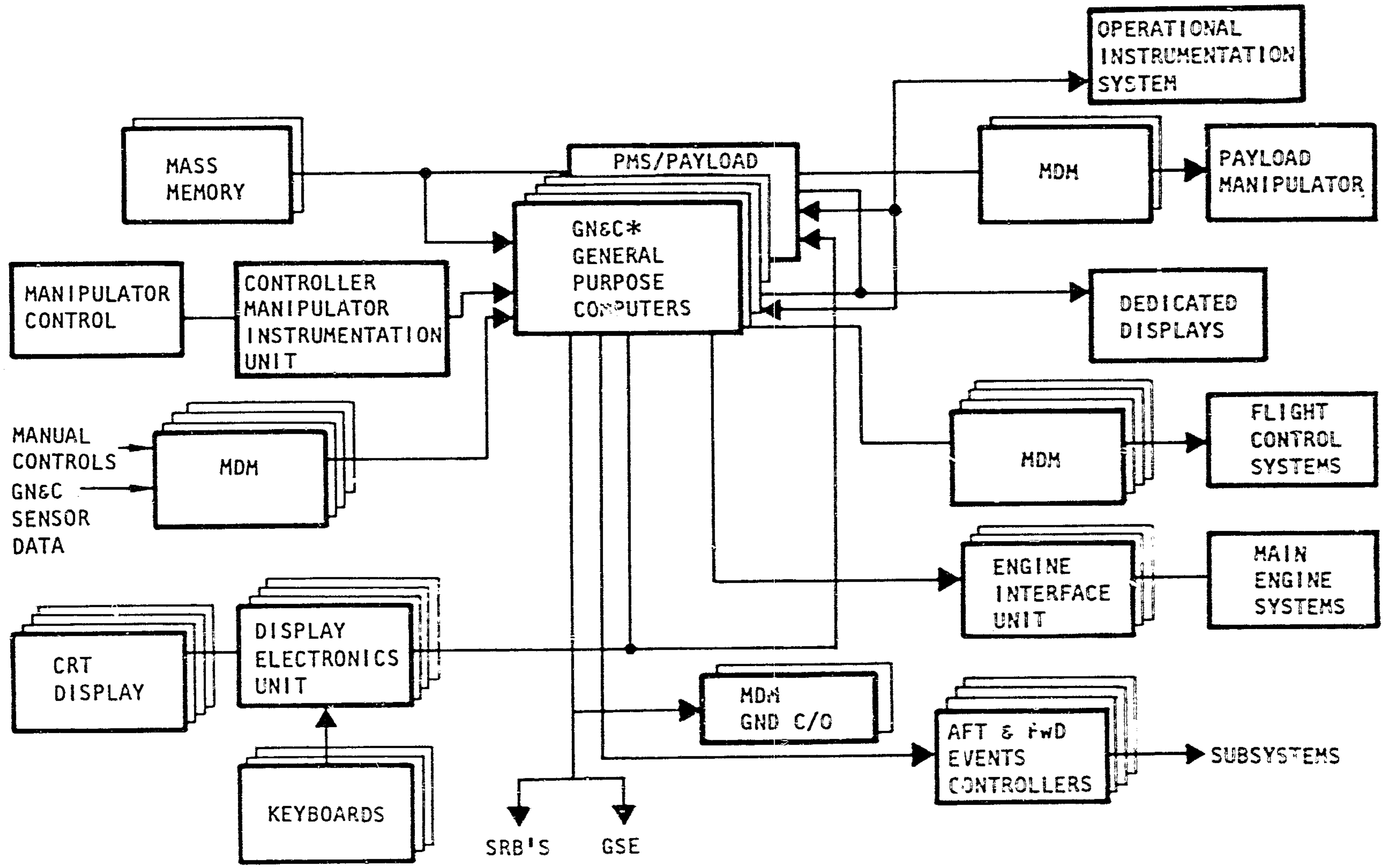


FIGURE 5-2

DATA PROCESSING AND SOFTWARE SUBSYSTEM BLOCK DIAGRAM



* FOUR COMPUTERS DEDICATED TO GN&C DURING CRITICAL FLIGHT PHASES. ONE OR MORE CAN BE RECONFIGURED FOR OTHER USES DURING NON-CRITICAL FLIGHT PHASES

FIGURE 5-3

ORBITER Ku-BAND RADAR/COMMUNICATION SUBSYSTEM

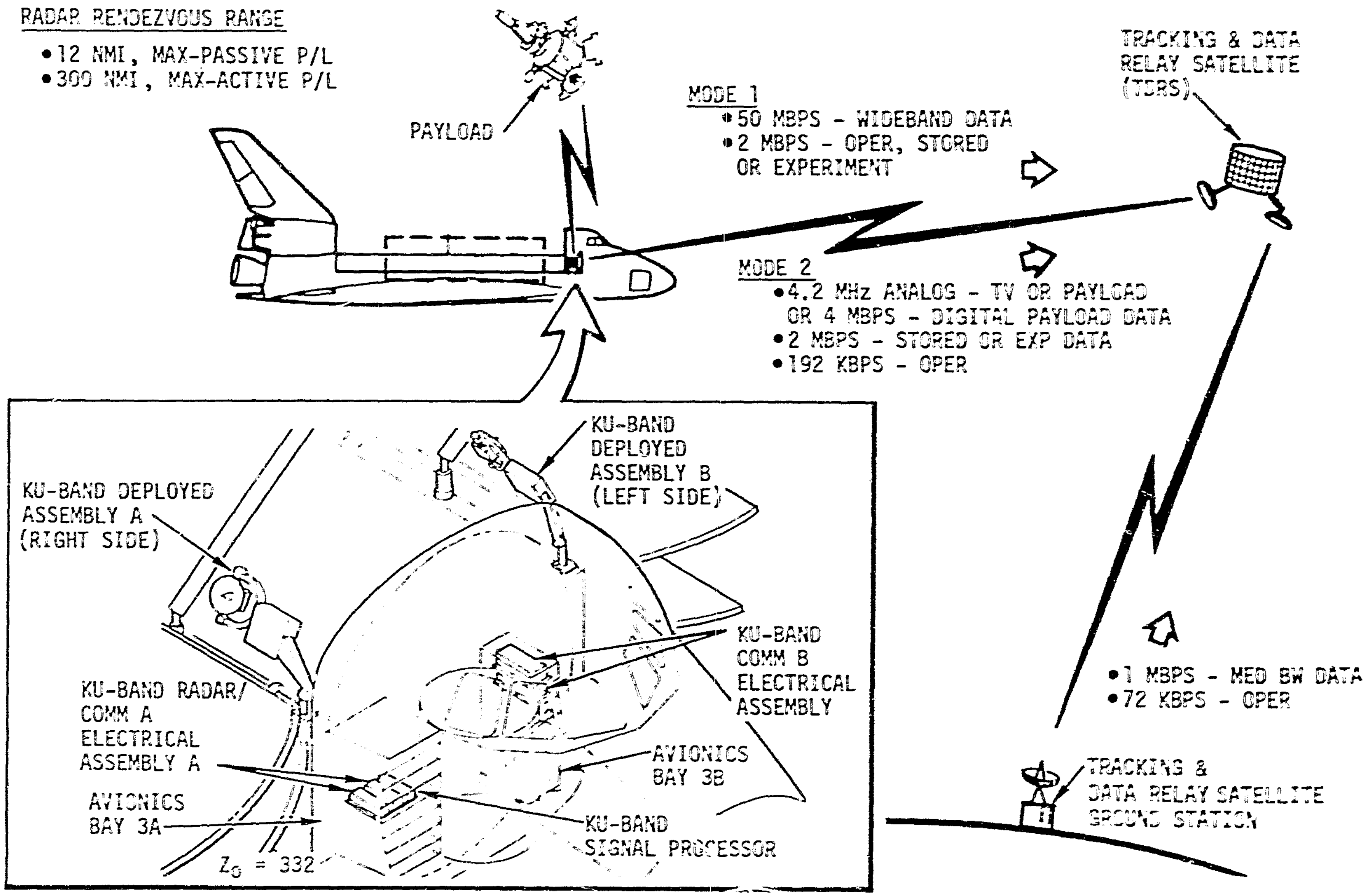


FIGURE 5-4

MSBLS-GS ELEVATION SHELTER AND EQUIPMENT

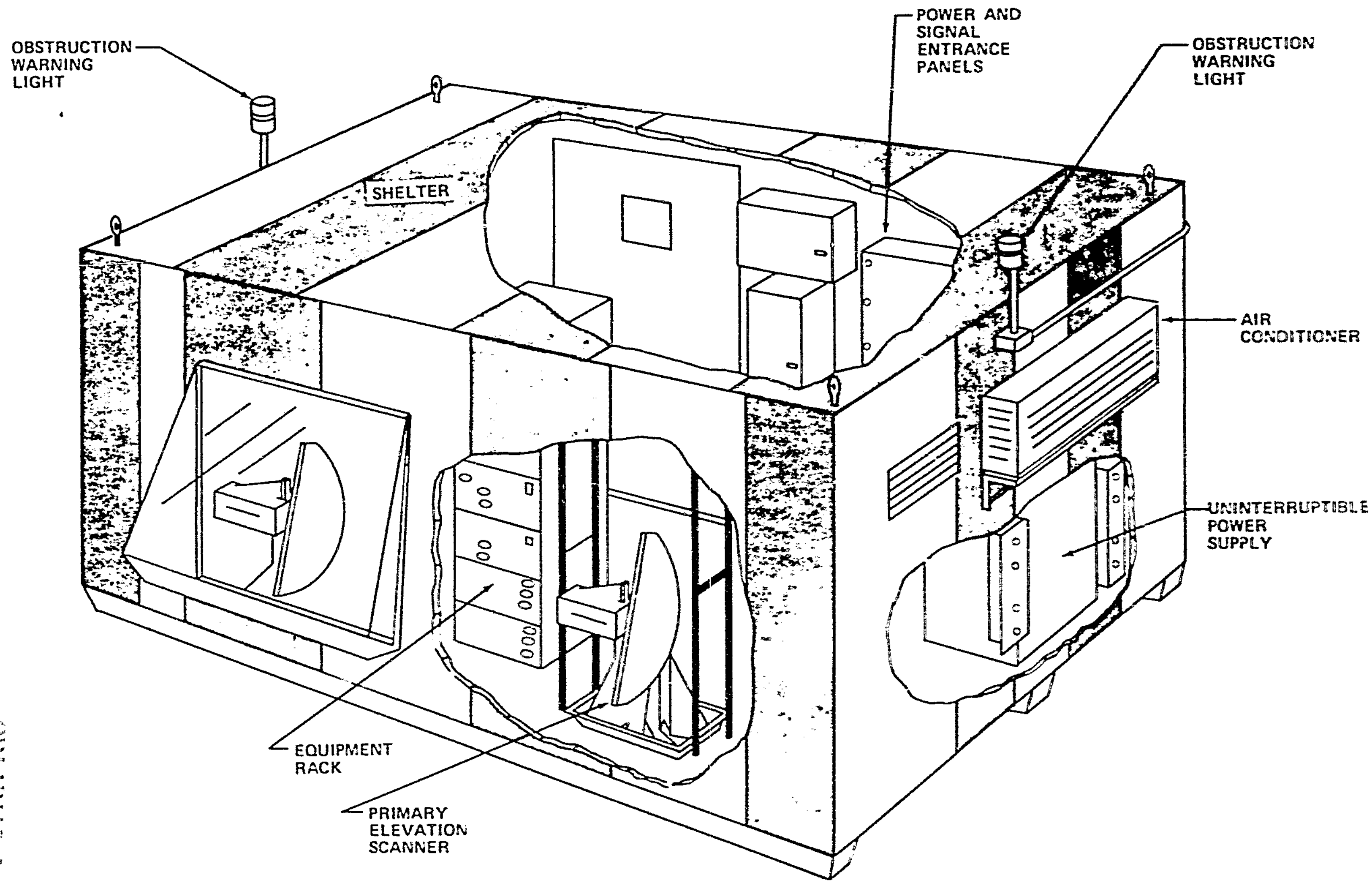


FIGURE 5-5

MSBLS-GS Az/DME SHELTER AND EQUIPMENT

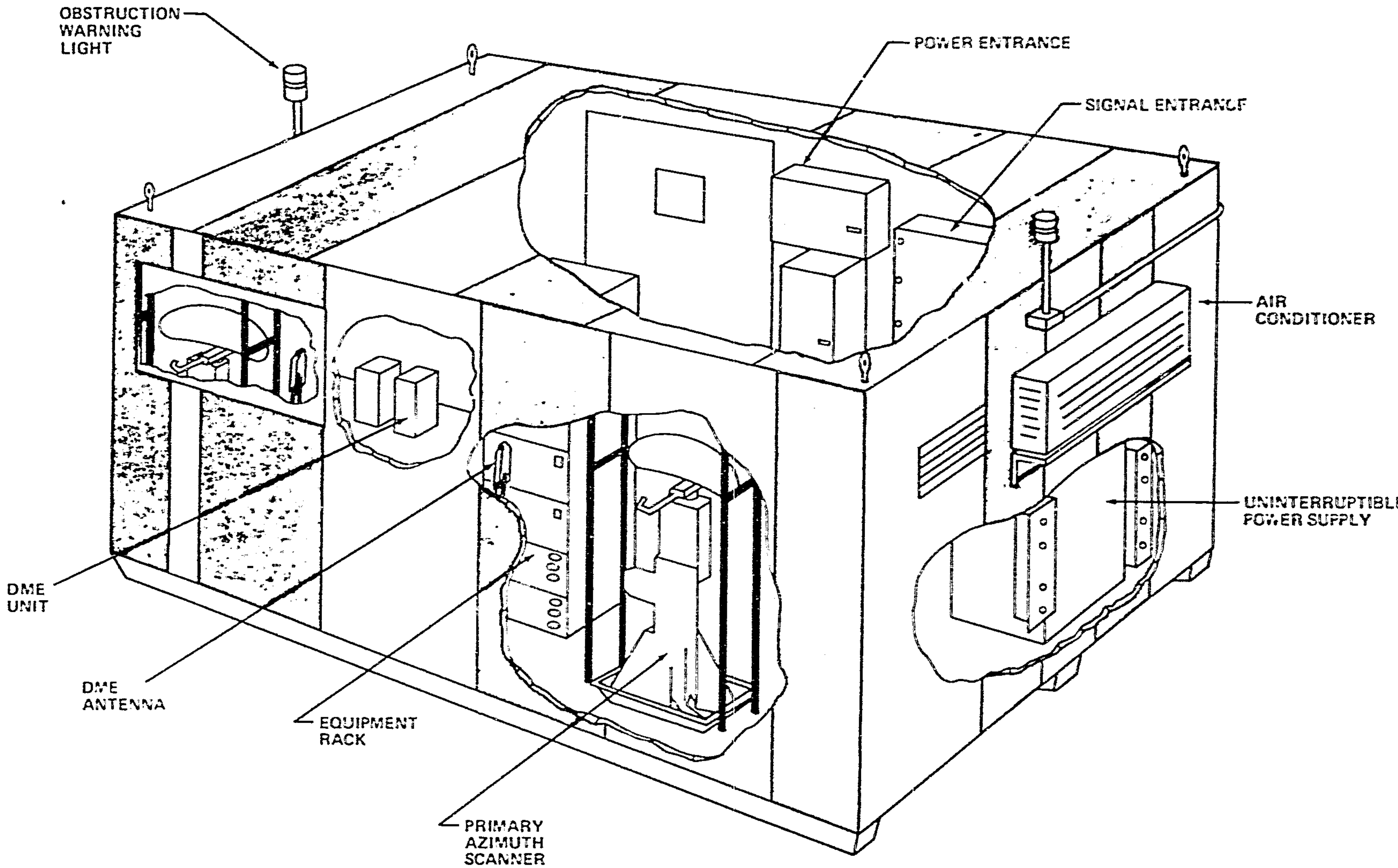


FIGURE 5-6

MSBLS MAJOR COMPONENTS AND rf LINKS

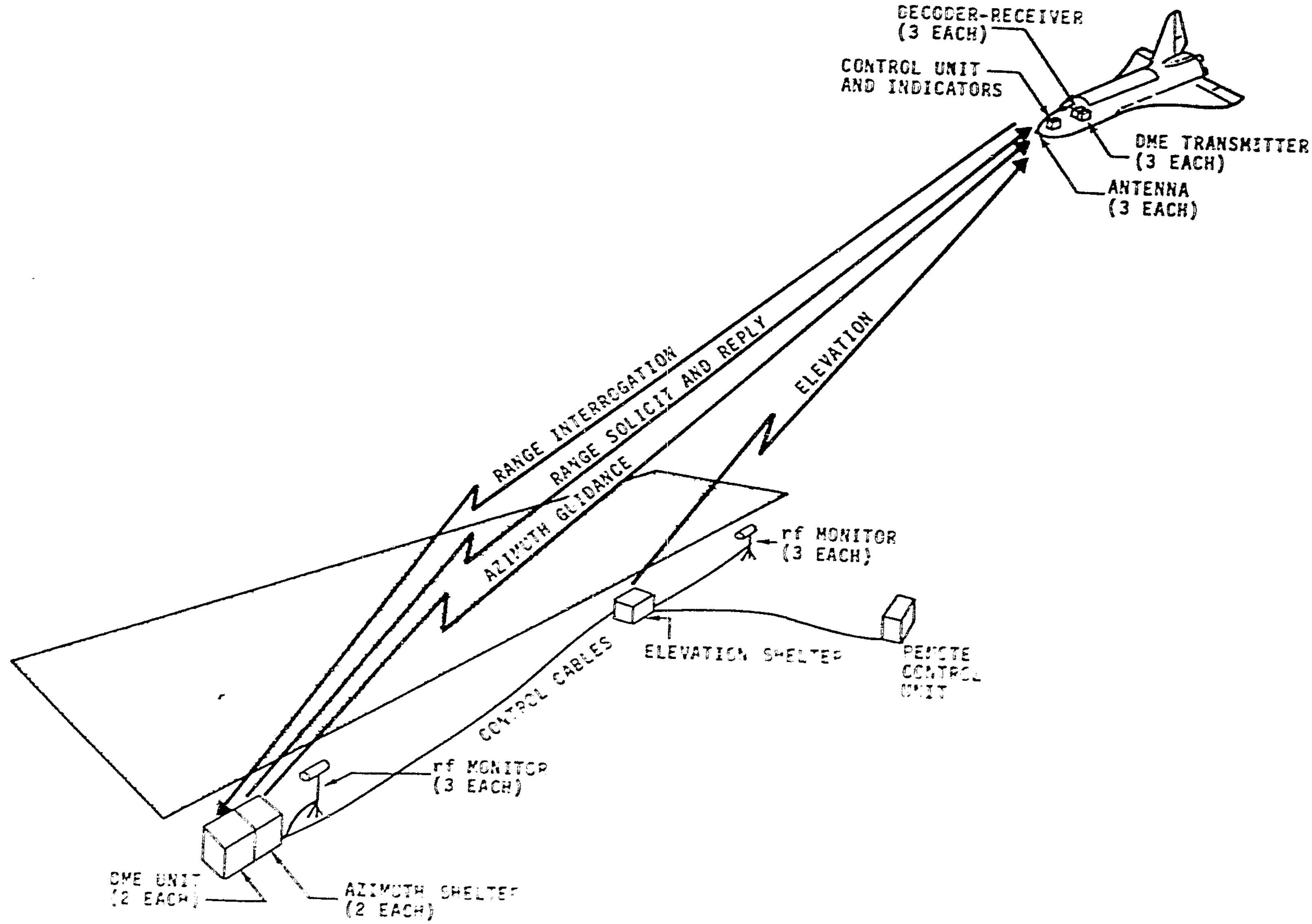


FIGURE 5-7

ADL AVIONICS SYSTEM INTEGRATION

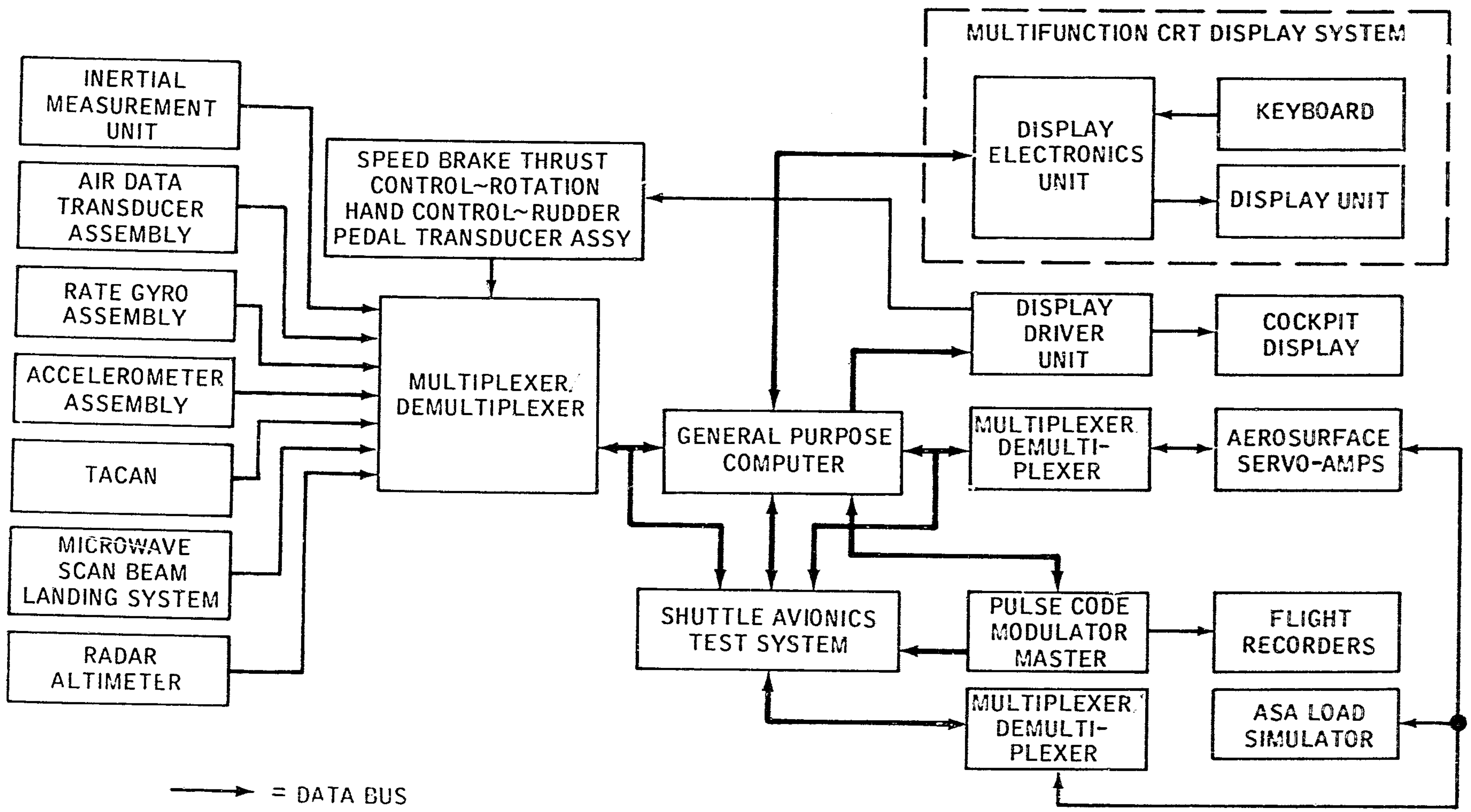


FIGURE 5-8

AVIONICS VERIFICATION CONCEPT FOR ALT

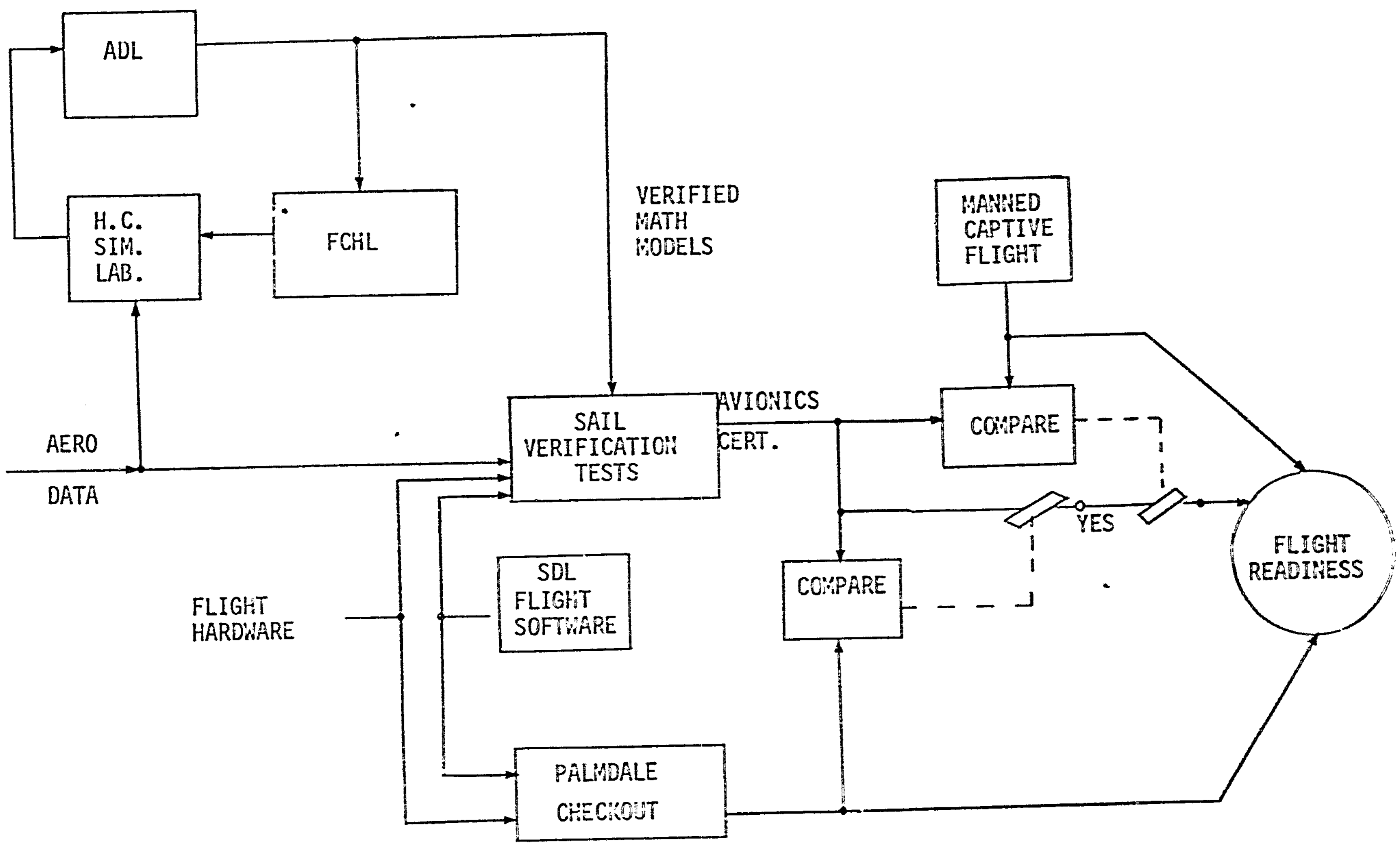
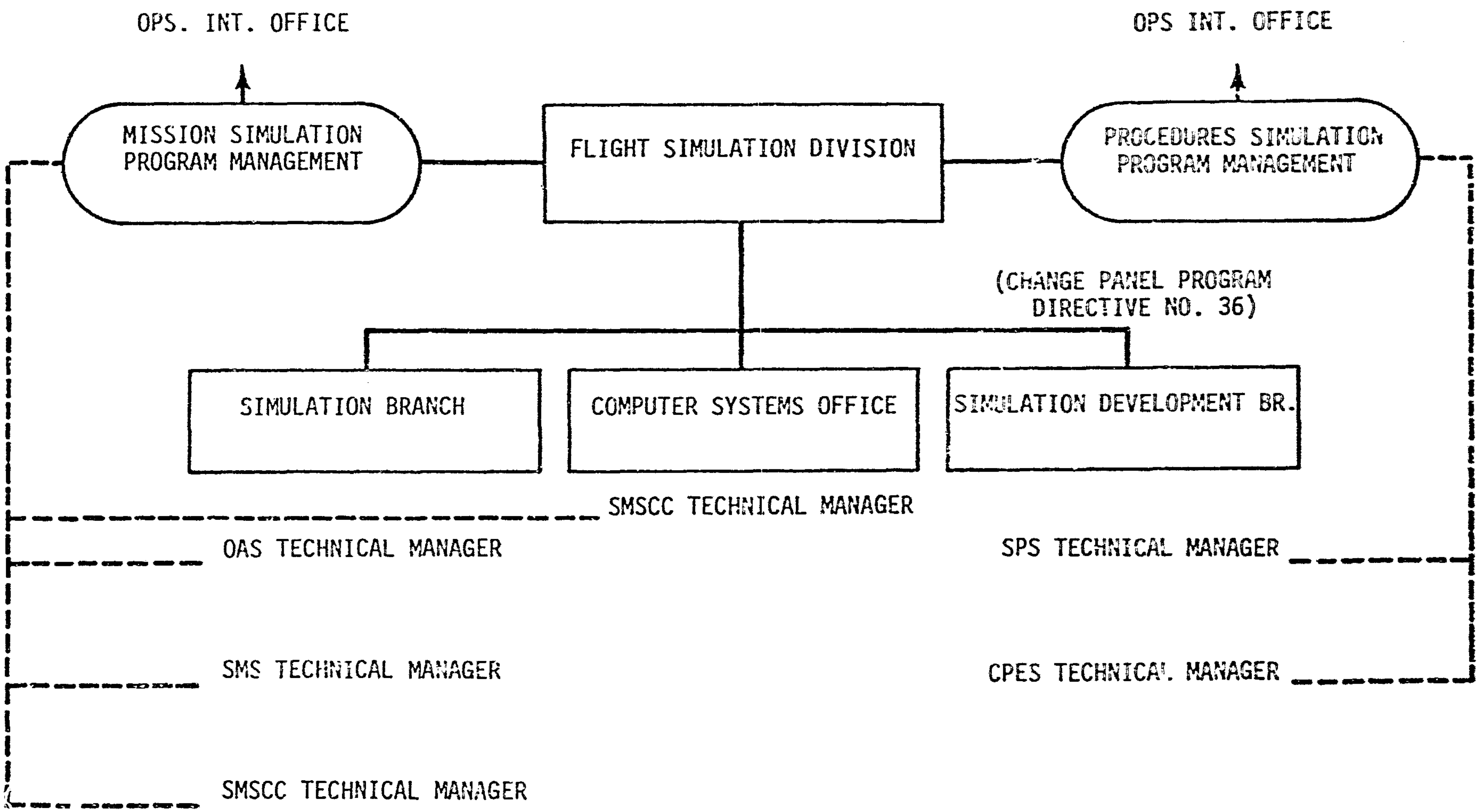


FIGURE 5-9

SIMULATOR OPERATIONS AND MANAGEMENT PROCEDURES



WBS ASSIGNMENTS/SIMULATOR

SIMULATOR SPECIFICATIONS AND PLANNING DOCUMENTS

SIMULATOR MODIFICATION CONTROL PROCEDURES

SIMULATOR OPERATIONAL PROCEDURES

SCHEDULING DIRECTORATE/DIVISION/BRANCH/SIMULATOR

6.0 RISK MANAGEMENT

6.1 Introduction

The first captive flight of the Orbiter is scheduled for the first quarter of 1977 and the first free flight of the Orbiter is scheduled for the third quarter of 1977. These significant milestones indicate the importance of an adequate risk management program in support of knowledgeable flight readiness decision making by management.

At the top level of review the risk management program asks the basic question, "Is the sum total of all of the accepted risks, that is the aggregate risk, commensurate with the benefits to be sought (e.g., first captive flight)?" The term aggregate risk is used in the sense that it is the synergistic total of the individual risks accepted by management on a one-by-one basis. The question of whether the aggregate risk is acceptable is a matter of judgment and is the prerogative of line management who must have both the autonomy and responsibility for such a decision. The Panel's purpose is to review the management system and assess whether it has the capability to do the job. To do this the Panel covered the following areas to obtain an integrated overview of the risk management system.

a. The current safety system for the identification of hazards, tracking hazards, analyzing them for resolution, risk assessment and acceptance procedures, and aggregate risk analysis.

b. The products resulting from the above activities and how they are used within the program, by upper levels of management and others responsible for the oversight of the Shuttle program.

c. The management system and its implementation to assure the appropriate use of "lessons-learned" from prior programs.

d. The "check-and-balance" system to preclude items "falling in the crack" including the role and work of the Crew Safety Panel and the new technical assessment groups.

e. The ability of these review system elements of the management, such as configuration control boards and technical reviews, to assure that individuals throughout the program can raise responsible safety concerns.

f. The role of the Cost Limit Review Board in reviewing safety issues.

g. The ability of the review system to assure safety coverage of technical items while providing risk information to management. Some of the specific questions asked in the Panel's review of these areas include:

(1) The controlled use of Teflon in areas with potential ignition sources.

(2) The library and control system for tracking and understanding the use of non-metal materials.

(3) Reliability and Quality Assurance methods to assure that fasteners meet design requirements for their application.

(4) The controls to preclude wire breakage where the wire is subject to repeated handling and/or substantial vibration. Special attention was given to the use of 26 AWG copper wire because of prior Apollo experience on the Lunar Module development Flight Instrumentation system.

(5) The system for follow-up and closure of Review Item Dispositions (RID's) resulting from hardware and software reviews and panel operations.

(6) The extent of analysis accorded to critical single-point failure items such as Orbiter elevon actuators, thrust vector controls, fluid manifolds, and so on.

(7) The adequacy of the landing gear deployment system on the Orbiter.

(8) Adequacy of the many door systems on the Orbiter to open and close as required.

(9) The control of "mandatory" program items, requirements, tests, etc. to assure there is adequate management attention when they are revised because of changing resource and schedule constraints.

Many aspects of hazards identification and risk assessment have

been discussed in other sections of this report. This is particularly true concerning "lessons learned" and their significance for safety of the design test and maintenance activities on the SSME, Orbiter TPS and software, ET insulation and SRB. This section, therefore, deals with the safety, reliability and quality assurance systems; how they are implemented; and typical examples of specific items to demonstrate these systems and to answer specific concerns raised by the Panel and NASA management during the past year.

Very little attention has been given by the Panel to the Shuttle-Payload interface and the associated safety implications because this is an area that will have to be covered at a later time.

6.2 Responses to Panel's Previous Annual Report

Almost all of the material contained in the Shuttle Program Office response to the Panel's Annual Report had some bearing on the safety aspects of the program. These responses, though have been distributed among the sections of this report as a part of individual element responses. However, one area is included here as Attachment 6-1 because of its broad scope.

6.3 The Risk Management System and Its Implementation

As would be expected the so-called risk management system is in reality made up of a number of on-going activities at various levels

of the program and at various locations as well as those efforts made by the dedicated reliability, safety and quality assurance organizations and personnel found throughout the Shuttle program. Ultimately the decisions regarding risk acceptance lies with the project and program managers within NASA Centers and Headquarters. While it is an accepted fact that "safety is everybody's business," one must first look at the system dedicated by name and job description to the reliability, safety and quality assurance disciplines and then look at the many long-term and day-to-day activities that feed and are fostered by this central core of risk management activity.

Rather than approaching this subject from the academic point of view it has been approached from the "real-life" view. In doing this, risk management as it applies to the Approach and Landing Test project and the early DDT&E Manned Orbital Flights has been the subject of the Panel's examination. The basic Panel questions are "How does the system really work and what are the products of such activities?"

6.3.2 Approach and Landing Test Project (ALT)

6.3.2.1 Background

The responsibility for deciding the acceptable degree of risk associated with the ALT flights is generally viewed as the exclusive province of senior management. From this standpoint, management

focuses on balancing risk against benefits on a macro-scale, but down the line innumerable risk-benefit micro-decisions are quite naturally made without recourse to higher management. However, prior experience has shown that some of these are recognized to be of major significance when their effects become visible. Sometimes it is too late for corrective action or it is late enough that corrective action is costly. Therefore, the Panel has attempted to review each type of NASA and contractor risk assessment activity where the purpose of these efforts is to warn the program of the possibility of problems; the resources and time required to resolve the problem; or the implications of accepting the problem. This review includes such questions as supervision factoring "lessons learned" into their work - are test planners and test conductors aware of safety concerns relating to the hardware they are to test and to fly. Background on the ALT project itself is found in Section 8.0, "Flight Test Program."

6.3.2.2 Safety Assessment

The Space Shuttle hazard identification and resolution system has been well defined for scope of the Orbiter 101, the Boeing 747 Carrier Aircraft and the supporting facilities and operations for the ALT project risk management system includes hazard identification, failure mode and effects analyses, risk analysis beyond initial FMEA, hazard resolution, risk acceptance criteria, and ultimately the decision to accept or

reject the risk. So one must review both the defined methodology as well as the day-to-day input which together produce the final risk assessment. In regard to the ALT project JSC and Rockwell are the primary managers with direct support from DFRC, Ames Research Center, Boeing Company, KSC and the JSC support contractor (MDAC). The following areas were sampled as being representative of the overall safety assessment/risk management "system."

6.3.2.2.1 Approach and Landing Test Critical Design Review (CDR)

The ALT/CDR was conducted during the period from March 11 to April 22, 1976. Many of the RID's and detailed discussions and decisions involved hazard identification and assessment of the overall safety system. This is, of course, a normal part of any major hardware/software review. In addition to this ALT/CDR, two other significant reviews were conducted on the Shuttle Orbiter 101 vehicle and they are important elements of the Alt safety assessment system. The Orbiter 101 CDR was conducted in October 1975 and the Orbiter 101 Configuration Review (Phase I) was conducted from February 23 through March 5, 1976. Because of their importance for safety all three of these reviews are discussed here from this point of view.

In support of the Orbiter 101 Rockwell provided a seven volume "Safety Analysis Report," SD75-SH-0135-001 through 007, dated 15 September 1975. These volumes covered six specific topics: (1) struc-

tures, mechanical systems, power systems, avionics systems, environment control and life support, crew stateion and equipment. In addition a summary volume for management was included with a copy of the detailed Rockwell "Reliability and Safety Desk Instruction No. 400-1" therein. Other documents used in the review include the following:

SD74-SH-0004	Shuttle Orbiter No. 1 Horizontal Flight Test SAR
SD74-SH-0168	Shuttle Orbiter 101 Delta PDR SAR
SD74-SH-0323	Shuttle Orbiter 102 PDR SAR
SD75-SH-0064	Shuttle System PDR SAR
NASA NHB 5300.4	(1D-1)

The review team also considered the "Failure Mode and Effects Analysis and Critical Item List," time/cycle/age life control lists and requirements; EEE parts use and qualifications; specifications and procedures for identifying and controlling special processes and more specifically all pressure vessels; configuration control system, specifications and handling of suppliers and subcontractors; failure reporting system and its implementation, etc. The following review team comments indicate areas that needed work and the program response to them:

FMEA/CIL — Suggested revisions to the hardware failure mode analysis regarding mode detection measurements and modification

	of mode effect. All comments have been incorporated into the FMEA system and documentation.
EEE Parts	Required Rockwell to obtain sufficient documentation from suppliers such as parts lists, stress analysis, and submission of irregular parts requests to JSC.
Safety Analysis	Requested additional hazard analysis on the loss of Body Flap Control as well as updates and clarifications all of which have been accomplished.
Test Programs	Required that certification plans to identify those items of hardware to be used in development tests and in qualification tests. Assured that SR&QA personnel would be on the control board for such tests as the Horizontal Ground Vibration Test.

A typical RID concerned the mechanical system in which the commander and pilot control pedals are linked together so that jamming of either station by debris can prevent operation of all pedal mechanisms. This safety concern was resolved by providing a protective

boot for all affected linkages. Another RID covered the relocation of the Hazardous Environment Breathing System mask equipment to assure the crew quick access to breathing air. These were relocated from the mid-deck position to the flight deck position.

With regard to electromagnetic compatibility of the hardware the Orbiter was baselined with a single point ground for the AC power and a modified multi-point ground for the DC power. The forward bay avionics has a DC power ground at station 76. The aft avionics bag has a DC power ground at station 1307. Some loads in the nose and aft fuselage are grounded to the structure. The use of a structure return for the DC loads in the AFT fuselage area saved weight. Structure power grounding is used on many aircraft currently in service. A specification is being developed that identifies the various EMI levels, and the power quality environment for the Payload bay. Special EMI testing will be conducted during the Shuttle development program to verify this environment as has been done on previous programs, including a comprehensive test of the Orbiter's electromagnetic environment and lightning protection on Orbiter 102 at Palmdale Assembly Facility in late Spring 1978.

The purpose of the Phase I Orbiter Configuration and Acceptance Review was to assess and certify the readiness of the Orbiter 101 subsystems and related GSE for individual subsystem testing. An important part of this review was the NASA walk-through conducted at Palmdale

to assess the condition of the vehicle. The walk-through team concluded that the hardware was very good and the personnel assigned to it were doing an outstanding job. The Phase II portion of this review concerned itself with the readiness of the Palmdale facility as contrasted to the readiness of the hardware subsystems.

An interesting RID from the CARR pointed to the hazard of shatterable materials in the Orbiter cabin. As a result, steps have been taken to resolve this issue by (1) compiling a complete list of all shatterable materials contained in the Orbiter 101 crew compartment, (2) performing a study to determine how shatterable glass can be protected so that it is contained if broken, and (3) determining if any of the items used in Orbiter 101 for ALT have found their way into Orbiter 102, and if so to assure an assessment of the hazard. When this data is in for management review, a decision will be made at a CCB meeting.

Further information on the Orbiter 101 CAR is found in SSV76-5-3 document dated 4 March 1976.

The Approach and Landing CDR conducted in April was followed by a Shuttle Carrier Aircraft (747) CDR in May 1976. Some items pertaining to the safety area that were brought out in this review are:

a. Prior to each SCA/Orbiter flight, a Flight Readiness Review will be conducted and supported by all elements of the ALT

project including the Rockwell/Boeing flight safety support personnel. When the ALT Project Safety Plan is finalized this suport should be defined.

b. The following documents are in process: (1) safety plans for the ALT site, (2) safety plans for 747 test operations, and (3) safety controls for 747/Orbiter Mating and Demating.

c. As a result of a RID in the October 1975 CDR, an Orbiter 101 Delta CDR was conducted for the Separation Subsystem between Orbiter and 747. As a result of the Delta CDR the Orbiter ALT program verification plan (MCR 2031) is now in work and will include verification plans for end-to-end checkout of the separation system. This plan is to be available for NASA review about June 30, 1976.

6.3.2.2.2 <u>ALT Mission Safety Assessment Document (JSC-10888)</u>

This document defines the results of the total safety analysis and risk management process. It identifies operational hazards that could compromise crew safety or damage the vehicles involved, evaluates risks for each operational hazard, provides an overall assessment of the ALT mission with respect to crew safety, and describes the status and actions necessary to "close" identified safety concerns. This becomes a major input to the Flight Readiness Review system.

The closed-loop methodology used to fulfill the requirements of

a Mission Level Hazard Analysis and the finalizing of the Mission Safety Assessment Document is shown schematically in Figure 6-1. The schedule for the ALT Mission Safety Assessment Report currently is:

Initial Document Release	June 1976
Final Document Release	February 1977
Up-Date Addendum (captive flight)	March 1977
Addendum for Free Flight	July 1977
Up-Date Addendum (free flight)	July 1977

6.3.3 Safety, Reliability and Quality Assurance for Ground Test and Orbital DDT&E and Operational Missions

6.3.3.1 Major Safety Concerns

There has been a need for a simple but useful means of providing program and senior NASA management sufficient visibility of Space Shuttle safety concerns, the means of resolution and the major accepted risks. This need is now being met by the "Major Safety Concerns Space Shuttle Program," (JSC 09990). This document is updated quarterly to reflect changes in status of major safety concerns and to add newly selected items. The latest issue available to the Panel, dated March 8, 1976 showed the following count:

Open safety concerns	19
Closed safety concerns	16
Accepted risks	7

Table 6-2 shows the listing of open safety concerns, closed safety concerns, accepted risks, and those design features that represent inherent risks which are considered to be justified. The details, of course, are contained in the referenced document.

This data enables the Panel to evaluate the process for determining which concerns are significant enough to place in this documen for management. The Panel has also indicated a continuing interest in all of this data because some continuing interest in all of this data because some safety concerns that have been closed or accepted may change in "value" due to other programmatic changes which impact them.

6.3.3.2 Content of Level II S, R&QA Activity

The work conducted at the Space Shuttle Program Management level (Level 2) at JSC is quite diversified. Table 6-1 lists some of the products of this work that have or will be published for information, analysis and control of various phases of the program from ground test through flight test and operational missions.

Some of the formalized plans such as the POGO Prevention Plan, JSC 08130 and the Contamination Control Plan, JSC 08131 play an important role in developing successful hardware that meets the requirements of the program specifications at Level I, II and III.

The materials control program, "MATCO," has been an ongoing pro-

gram since the early days of the Shuttle Program. The contents of the program are constantly being updated to assure timely and complete data to support all levels of the program at all affected NASA Centers and contractors. Some of the requirements documents that apply directly to this work are:

Level I (NASA Headquarters), NHB8060.1A, "Flammability, Odor, and Offgassing Requirements and Test Procedures for Materials in Environments that Support Combustion." This is also applicable to those payloads that are placed in the Orbiter habitable areas.

Level II (JSC) SE-R-0006A, "NASA-JSC Requirements For Materials and Processes."

Level III (MSFC) MSFC-STD-506 "MSFC-NASA Standard Materials and Process Control."

Level III (KSC) - Document is not known by the Panel.

Rockwell International, SD72-SH-0172, "Space Shuttle Orbiter Materials Control and Verification Plan."

Rockwell International, MC999-0096D, "Materials and Processes Control and Verification System for Space Shuttle Program."

The Panel has reviewed some of the MATCO program and it will continue to review this area to assure that the methods for implementation are adequate to the program needs. In using MATCO information to evaluate materials actually used on the Shuttle, the program must have

an effective configuration control system to assure that the materials evaluated in the design phase or in fact used on the flight vehicle and any materials subsequently introduced into the program are also carefully evaluated. Thus the periodic configuration control board activities examine the materials problem for every change made to the hardware and design reviews.

As part of NASA's continuing effort to establish uniform and complete policy and responsibilities on areas that affect safety and mission success Headquarter's has issued a Management Instruction on NMI 1710.3, dated April 8, 1976, "Design, Inspection, and Certification of Pressure Vessels and Pressurized Systems."

Attachment 6-2 is a letter covering the potential problems associated with nuclear detonations. It is indicative of some of the areas of safety examined by the Panel to assure program attention to as many details as possible.

Much of the material that follows is also a part of the work done in the safety, reliability and quality assurance efforts discussed above. However, it is discussed separately because of the Panel's interests.

6.3.3.3 Flight Termination System

The Flight and Ground System Specification (Volume X of JSC 07700) was revised April 12, 1976 (Change No. 30) so that the requirements for

range safety now reads as follows:

"The Flight Termination System shall comply with the range safety Flight Termination System requirements of AFETRM 127-1 and SAMTECM 127-1. The flight vehicle shall comply with the range safety requirements of SAMTECM 127.1. In those instances where adherence is judged to be inappropriate from either an operational or technical standpoint, such instances shall be brought to the attention of the DOD/NASA for resolution."

This guidance is developed in greater detail for those sections of the document that deal with the specifics of mission abort operations functions, flight system design on the SRB and ET including destruct safing. The current effort is to baseline mutually acceptable concept for NASA/DOD Space Shuttle Range Safety and define the mode of resolution for problems that subsequently develop. The current hardware safety system is called a "Triplex" system in that each SRB and the ET have destruct systems on-board. There is sufficient redundancy to assure proper operation in either the armed mode or the safe mode. Items of interest that will be examined by the Panel in the near future include the following: the agreed-to baseline concept; current open problems regarding the design, installation, and utilization of such a system; any schedule and procurement constraints; current design options and their advantages and disadvantages; and

constraints on operational and DDT&E missions.

6.3.3.4 SRB Fracture Control Board

Recognizing the importance of fracture control of SRB reuseable components, MSFC established an SRB Fracture Control Board which held its first formal meeting on October 8, 1975. The Board is set up as shown in Figure 6-2. This board has undertaken a number of concurrent activities to assure both that every aspect of fracture control for the SRB is properly accounted for and not information resulting from this effort is furnished to other Shuttle activities for their use. Each of the major contractors on the SRB have developed fracture control plans which are either being implemented or in process of being implemented at this time. These plans provide for the following functions:

a. Development of fracture control technical guidelines and directions.

b. Establishment of a contractor Fracture Control Board. The Board reviews and approves all fracture analyses, fracture control test data, and component control plans. Finally it monitors compliance, and establishes necessary corrective actions and reports. It reports to the NASA SRB Fracture Control Board and is also a major support for the Material Review Board.

The MSFC board, in addition to working with the contractor units,

does its own independent analysis and testing and maintains a detailed list of "technical concerns and action items" and assures their resolution.

6.3.3.5 Abort Planning for Shuttle Flights

Based on the material provided to the Panel during its reviews of the abort area some concerns have surfaced. These are in regard to the timeliness and depth of studies to define abort capabilities, and supporting the assessment of aggregate risk for any given mission. The Level I, II and III documentation sets forth requirements in the general area of aborts as well as specifics relating to intact abort, contingency aborts, and appropriate loss of critical functions. Such abort analyses are directed primarily at the DDT&E and operational orbital missions, although such analyses apply to the ALT missions as well. Abort planning and activities associated with ALT are covered in Section 8, "Flight Test Program."

In addition to the many efforts going on at both NASA Centers and the contractors a number of Level II panels and review teams have been examining this area in some detail. Some of these are the Crew Safety Panel, the Systems Integration Review Teams, Flight Operations Pane, SR&QA Panel, Ascent Flight Systems Integration Group, and the Abort Panel.

The Level II specifications have specified the requirements for

intact abort and the intact abort modes. These same specifications have specified the requirements for contingency abort and the contingency abort criteria. However, the contingency abort modes have as yet not been defined. Attachment 6-1 is the Shuttle Program Office response to the Panel's previous Annual Report covering this particular area of concern. An area of concern to the Panel has been the abort capability during the early stages of ascent when the Solid Rocket Motors and the Orbiter Main Engines are all burning.

The Level I requirement (JSC 07700, Volume X) is that potential failures in a system that could cause loss of critical functions will be eliminated by including appropriate safety margins or redundancy levels in the design. In addition crew ejection seats will be provided for the initial series of Shuttle OFT launches until the flight worthiness of the launch system has been demonstrated. These ejection seats as baselined for the orbital flight test program provide crew escape capability up to approximately 80,000 feet. The SRB thrust termination capability and the use of abort rockets were included in the early Shuttle baseline. However, they have been deleted by Level II action. The PCIn S00015 deleting the abort solid rocket motors was approved in 1972. The PCIN S00040 eliminated SRB thrust termination in 1973.

6.3.4. <u>Special Topics</u>

6.3.4.1 Lessons Learned

The Panel reviewed the management system to assure the appropriate application of lessons learned from prior programs.

The task team met with personnel at every level of JSC, KSC, MSFC, Rockwell, and Rocketdyne. They were supported by the efforts of the others who also focused on the application of lessons in areas under their review. The Panel as a whole then discussed the system as they found it with Shuttle management.

Assurance that lessons are in fact being implemented is accomplished through:

a. Lessons are incorporated into such documents as design manuals, process specifications, etc.

b. SR&QA conduct audits to assure lessons are being implemented where proper to do so.

c. Contractors' reports on their implementation of lessons at quarterly reviews and other in-house meetings.

d. The Aerospace Safety Advisory Panel reviews this area on a periodic basis at various NASA and contractor sites.

The Panel is also interested in assuring that lessons learned on the current Shuttle program are examined and applied as appropriate here and now. Here is an example of how experience is captured, passed on, and finally utilized. This comes from the External Tank

data reviewed and discussed at MSFC in early Fall 1975. The Martin-Marietta team working with JSC reported, at that time, the data as presented on Table 6-2. In addition to the many NASA documents they found 67 other lessons from MMC and Airforce documents as well. Based on the material discussed at that time the MSFC area showed the following brief statistics:

Element	Total Number of Lessons Applicable	Applying Directly	Meeting the Intent
External Tank	546	520	26
SSME	160	148	12
Solid Rocket Booster	81	80	1

6.3.4.2 Wire Usage and Implementation on Shuttle Elements

As the result of his Apollo experience the Deputy Administrator requested the Panel to review the use of 26 AWG wire and the use of teflon on Shuttle.

The lesson learned is cited in NAA Technical Note, D-7598, dated March 1974, "Apollo Experience Report - Development Flight Instrumentation."

"In LM-1, the scarcity of available space and the consequent miniaturization of certain DFI components led to the design of a central signal-conditioning unit that had a density of 1600 connector pins over a 45-square-inch faceplate. ..... and the mating cable

harness consisted primarily of No. 26 AWG wire. After a series of requirements changes and trouble-shooting procedures that involved moving and opening the signal conditioning unit, some of the wires in the harness became fatigued and broken. This problem was also manifested in the harness in other areas where cable movement was excessive. The situation deteriorated to the point at which attempts to rectify certain cable breakages precipitated further breakages in adjacent areas. ..... From the cabling problems cited, three conclusions can be drawn. First, high-density wiring configuration should be avoided. Second, signal conditioning should be decentralized or made remote so that low-density connector configuration can be achieved to permit easy access and repair and result in inflexible bundles of cables. Third, the DFI system involved frequent equipment changes; therefore, it should use a heavier gauge wire than the more permanently situate, operational-type equipment."

Based on data received to date the use of this guaging on Shuttle in wiring and connections is controlled as follows:

a. Of the approximately 910,000 feet of wire in the Orbiter, most of it consists of 22-AWG and 24-AWG. For DFI, signal wiring the Orbiter 101 contains about 30,000 feet of the new 26-AWG and Orbiter 102 about 70,000 feet of it.

b. The 26AWG, when used on Shuttle elements, is made of

an alloy of copper having a considerably higher tensile strength than the copper wire referred to in the above Apollo usage. Thus the new 26-gauge wire is closer in strength to the old 24-gauge wire. In general the 24 and 26 gauge wire is now stranded nickel coated high-strength copper alloy. For 22-AWG and larger the conductor is copper as before.

c. Wherever possible high-density wire configurations are being avoided. Signal-conditioning is decentralized in a manner which supports the use of low-density connector configurations so as to permit easy access and reduced chance of wire fatiguing or bending.

d. Pin-socket connectors have posed many problems in the past due to the need for near-perfect alignment, proper final seating, and the correct electrical circuitry between the lines to the pin and socket. A somewhat different design is being used by the MSFC elements in that the fixed-portion of the connector now has the pins and the mating portion is the socket. This appears to provide for easier installation and better mating of the connectors.

e. Certain sensing devices, such as strain gauges, use pig-tails of wire in a gauge size required to meet the size of the sensor and the connection to he main wire-run. These are ?5-AWG in many cases, but are not more than 8 to 12 inches in length and are rigidly fastened to the associated structureat more than one point

along the length of the wire.

f. All wiring on the External Tank is 22-AWG or larger except the DFI data-bus wire which is 24-AWG and the one foot long pigtails on about 70 strain gauges which are 26-AWG.

g. The Solid Rocket Booster uses 26-AWG only as required for sensor pigtails. Non-shielded wires are 22-AWG or larger. Shielded wires are 24-AWG or larger. The data-bus wire is 24-AWG.

h. The Space Shuttle Main Engine uses 22 AWG or larger except where there are short pigtails

There is controlled use of Teflon insulated wire on the SSME and the SRB. The use of Teflon inside the ET tanks is still being studied. Kapton covered wire is used on both the External Tank and the Orbiter wherever possible. It is a much stiffer and abrasion resistant material. Cable or harnesses use the Kapton covered wire to act as a sort of "back-bone" for the wire bundles because of its tougher characteristics.

6.3.4.3 <u>Quality Control of Screw Threads</u>

The Panel during its fact-finding sessions reviewed the quality control system on fasteners and their application. It was determined that contractors on the Main Propulsion System survey their manufacturers of flight hardware fasteners and sample incoming lots of fasteners during receiving inspection. They are using either

plug and ring gauges or single element gauging to assure that requirements of the screw thread specifications are being met. It appears that all contractors working with MSFC are using the same controls now as they have in past programs with NASA.

As an example, Thiokol, which manufactures the Solid Rocket Motors, audits or surveys fastener manufacturers each six-month period to assure that inspection records are maintained. The single element gauging of threads meets the requirements of MIL-S-7742 and MIL-S-8879. Thiokol then samples incoming lots during receiving inspection per MIL-S-105 using plug and ring gauges.

On the other hand the External Tank manufacturer, Martin Marietta Corporation at Michoud, does not ordinarily survey their fastener suppliers. They perform receiving inspection per MMC Quality Receiving acceptance plans that specify either 100% inspection or an adequate sampling plan. The single element gauging system is used both in this receiving inspection as well as in laboratory shear and tensile tests.

The contractor for the Main Engine, Rocketdyne, surveys their suppliers yearly and samples each manufacturing lot. The MIL-S-7742A and MIL-S-8879 requirements are on contract. There is thread snap gauge inspection on external threads, as well as visual inspection for uniformity, damage, and so on. This is done on a random basis with

major diameters measured by micrometers. MIL-S-8879 threads are inspected on an optical comparator for root radius. Internal threads are checked for size using thread plug gages and are visually inspected for uniformity, damage, etc. Material tests are performed in the laboratory as well.

No failures attributable to nonconforming screw threads has been found in these or associated contractors as a result of a detailed search of back records.

With regard to the Orbiter it is understood that almost all of the suppliers of threaded fasteners use a single element type gage to control their manufacturing process. The two suppliers that do not use the single element type gage are suppliers of lock nuts which are purposely distorted to provide a locking capability. Threaded fasteners which have material strength levels above 160,000 psi are required to meet military and contractor specifications which contain both functional and macrosection criteria. Criteria include single element as well as functional and special measurements or inspections. Laboratory tests are conducted on sections as well. Fasteners with strength levels below 160,000 psi are required to meet military specifications on thread gaging to assure proper fit and function and to assure that the pitch diameters, root diameters, minor diameters, etc. are within specifications. Optical projection is employed for root radius and minor diameter verification. Since all

Orbiter threaded fasteners are listed in the Orbiter project parts list, other parts can only be procured by the prime contractor or its subcontractors after specific engineering approval.

6.3.5 Addendum

As a result of these reviews, suggestions for future examination have been put forth, these include:

a. Is there value in co-locating additional S,R&QA personnel within the Shuttle Program Office area reporting directly to the S,R&QA office at Level II. In this way they might provide better day-to-day support to the S,R&QA Panel and other related activities.

b. The degree of participation by NASA Centers and all NASA prime contractors in the activities of the S,R&QA Panel work.

c. The experience gained from the landing gear design problem which was exposed during the Orbiter 101 test and checkout work at Palmdale should be provided to all elements of Shuttle.

d. Determine the background of the landing gear uplock hook failure from the viewpoint of S,R&QA activities at both the contractor and at NASA.

e. The degree of participation by the S,R&QA personnel in the establishment of test plans and their implementation.

6.4 Additional Mission Safety Assessments

The following material further clarifies material in three areas: (1) ALT mission safety, (2) Requirements Reviews, and (3) Abort and Contingency Plans.

6.4.1 ALT Mission Safety Assessment

The mission safety assessment document is in review at this time. The principal open and closed safety concerns have been discussed for the Shuttle Carrier Aircraft, the Orbiter and the operations phase. The accepted risks for the carrier aircraft, the orbiter, GFE and operations are also shown. This document, JSC 10888, will be updated as required. As an example, the list of concerns and risks for the "Operations" phase are:

1. Open Safety Concerns (Implementation of corrective measures has not been accomplished)

   a. Lack of hazardous gases vent capabilities in the Orbiter hanger

   b. Shuttle Carrier Aircraft empennage/aft fuselage buffet with tailcone off.

   c. Orbiter landing gear deployment during captive flight.

   d. Incompatibility of the carrier aircraft with hydrazine fuel.

2. Closed Safety Concerns

   a. Hazardous environment around the carrier aircraft.

   b. Excessive Orbiter wing loads during mated flights.

3. Operations Accepted Risks

   Incompatibility of the carrier aircraft with ammonia, and possible damage to the vertical stabilizer by ejection seat system outer Orbiter panels while mated.

6.4.2 Risk Assessment To Support Requirements Reviews

As in those manned programs preceeding it, the Shuttle program

periodically takes the time to review and clarify the program requirements in light of the most current status and performance estimates for the hardware and software and the constraints of the resources available to meet program objectives. A parallel and independent S,R&QA review is made with respect to every change in requirements put forth for consideration. The degree of this review is not fully known. These safety oriented reviews and assessments are provided so that technical personnel and senior management can consciously consider the impact of such changes before making their decisions. As an example, the flight safety and S,R&QA organizations examined some 340 candidate changes during a recent requirements review covering a period of several months. They determined that about 185 of the candidates had no safety impact, while the impact of the other 155 was identified for management consideration.

6.4.3 Abort And Contingency Planning

To understand the current status of abort and contingency planning efforts and hardware/software implementation the Panel examined the history of this work. This included a review of the decision process to eliminate both the SRB thrust termination and the use of Abort Solid Rocket Motors. Basically these steps were taken because (1) the Abort Solid Rocket Motors added additional mechanical failure modes and large weight penalties, and (2) there were no credible SRB failures during the SRB burn period because of the reliability of such rocket motors.

Further, the Orbiter is to be equipped with two SR-71 aircraft ejection seats for the first four orbital flights (OFT). These have been qualified for and used under conditions exceeding the Shuttle ascent trajectory in terms of mach number, velocity and dynamic pressure. The ejection seats provide an escape capability from the pad to approximately 80,000 feet with these limitations:

1. The seats probably could not be used for an escape off-the-pad with engines running or in the event of an external tank blowup and resultant fireball.

2. They probably would not survive a very rapid breakup of the vehicle in the event of an explosion.

3. They also cannot be used during the last 30 seconds of the 120 seconds of SRB burn or between 80,000 feet and 140,000 feet.

ATTACHMENT 6-1

> It is important that senior program management review both the scope and results of safety analyses to reinforce early resolution of risks. Similarly, attention should also be given to the scope and results of technical management audits to assure that such systems as described to the Panel are being applied properly. Two examples are Configuration Management and Material Control.

Response: Safety Analyses are being conducted at the project and program level. Significant "safety concerns" are published separately with rationale for senior program management visibility and review. Critical Items Lists, which include single failure points that could cause loss of vehicle, crew, or mission are to be baselined at the program level, with changes to the baseline approved at program level. In addition, a Mission Assessment Report will be prepared for senior program management visibility and review at the program CDR time period.

Technical surveys and audits are conducted according to schedules established by project and program elements which may cover several technical disciplines or a specific area, e.g., configuration management and material controls. Configuration management is usually covered in conjunction with the annual S,R&QA surveys. Presently, the materials control area is receiving special attention. A survey was conducted in materials in June 1975 of the Orbiter contractor (Rockwell/Space Division). Another survey is planned for the external tank contractor in September 1975, and one for the Solid Rocket Booster contractor (Thiokol) in October 1975.

Contingency analyses especially for aborts, ditching, landing accidents, and range safety should be completed early enough to assure design solution rather than operational work-arounds.

Response:

Aborts

(a) The present abort analysis effort is being concentrated on those cases with the highest probability of occurrence. These are the intact abort cases and include the following:

1. Loss of thrust from one SSME
2. Loss of TVC for one SSME
3. Loss of thrust from one OMS engine
4. Loss of TVC for one axis of SRB

The aborts with a low probability of occurrence are referred to as the contingency abort cases. These cases are being studied, but to a limited degree, in consonance with their low probability of occurrence. Contingency abort cases include the following:

1. Loss of thrust from two or three SSME's
2. Loss of TVC for two or three SSME's
3. Loss of TVC for two or more axes of an SRB
4. Premature Orbiter separation
5. Failure to separate SRB from Orbiter/ET

For certain situations, it is not practical to provide for abort solutions. For these cases, appropriate safety margins and high factors of reliability have been included in the Space Shuttle design to preclude their occurrence. These cases include the following:

1. Major structural failure
2. Complete loss of guidance and/or control
3. Failure to ignite one SRB
4. SSME or SRB hardover
5. Failure to separate Orbiter from ET
6. Premature SRB separation

Ditching

(b) Orbiter ditching tests have been conducted at Langley Research Center. Based on these tests, the Orbiter should be able to land safely on the water, assuming no major structural breakup. Preliminary structural analysis indicates structural breakup will probably not occur for reasonable ditching conditions. There is a possibility of the side egress door jamming during ditching. Alternate ways are being studied to evacuate the Orbiter in case the egress door is jammed during ditching.

Landing Accidents

(c) Analysis is being conducted by JSC and LRC on the energy absorption capability of the Orbiter during landing accidents. The purpose of the analysis is to determine the ability of the crew compartment aft bulkhead to absorb payload loads resulting from landing accidents.

Range Safety

(d) The Range Safety System PDR is scheduled for October 15 through November 7, 1975. This system, baselined over a year ago, has not yet been approved by the Air Force Eastern Test Range (AFETR). In order to resolve the issues raised concerning range safety requirements, a joint NASA-USAF Ad Hoc Committee is being formed to conduct a technical analysis of the hazards of Space Shuttle flights, both developmental and operational, and to trade off hazards against related launch azimuth constraints and vehicle reliability in order to determine a logical approach to assuring public safety. Alternatives will be recommended to NASA management and the Commander, AFETR, for decision.

ATTACHMENT 6-2

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO
ATTN OF

JAN 1 - 1976

RECEIVED
MRC
20 JAN 197

Mr. Howard K. Nason
President, Monsanto Research Corporation
800 N. Lindbergh Boulevard
St. Louis, Missouri 63166

Dear Howard:

This is in reply to your letter of December 23, 1975, concerning potential dangers to Space Shuttle missions from nuclear detonations.

The Space Shuttle Program has taken the potential hazards of nuclear activity into account as part of the ongoing program effort. At JSC a Space Radiation Analysis Group is responsible for defining and assessing all potential (pre-flight) and actual (real time) radiation environments which may be encountered on Space Shuttle missions. This effort, as part of the JSC/Rockwell contract NAS-14000, includes a subcontract with Radiation Research Corporation, Ft. Worth, TX, and is being administered by the JSC Radiation Constraints Panel. For Space Shuttle, as in previous programs (Skylab and ASTP), part of this responsibility is the assessment of potential hazards from atmospheric and exoatmospheric nuclear detonations.

The assessment of both immediate and long term hazards to Space Shuttle from nuclear detonations includes:

1. Prompt effect computation (flash blindness, neutrons, x-rays, etc.)

2. Enhanced radiation environment definitions with respect to time, altitude, position, yield, etc.

3. Crew and equipment exposure projections with respect to time and radiation type.

4. Biological effects/crew health evaluation.

The most important aspect of this effort is the refinement of real-time support procedures which will allow for timely data acquisitions, hazard assessment and implementation of related mission rules to insure minimum impact to Space Shuttle crews and mission objectives. For example, if there is advance warning, the line-of-sight situation is avoided, or, if an excessive radiation environment is encountered, the mission will be terminated and re-entry and landing accomplished as soon as possible.

The liaison necessary to support this effort has been established through the Office of DOD and Interagency Affairs. The Office of International Affairs also plays a part in advising appropriate countries of NASA flight plans for manned missions to help minimize the likelihood of an inadvertant encounter with a nuclear event.

As you can understand, there are many aspects to this kind of an effort. In connection with the planned Aerospace Safety Advisory Panel meeting at JSC next month, you might wish to talk to Rod Rose who could give you further details.

Sincerely,

John F. Yardley

John F. Yardley
Associate Administrator
for Space Flight

cc:
AD/Dr. George Low
APA/Carl Praktish
Gen. Warren D. Johnson, USAF

TABLE 6-1

IMPLEMENTATION STATUS - LESSONS LEARNED AS APPLIED TO THE EXTERNAL TANK (Mid-1975)

DOCUMENTS	TOTAL NO. LESSONS APPLICABLE	ENGINEERING APL'D*	ENGINEERING IMPL.*	PRODUCT ASSURANCE APPL'D	PRODUCT ASSURANCE IMPL	PRODUCTION OPERATIONS APPL'D	PRODUCTION OPERATIONS IMPL	MATERIAL APPL'D	MATERIAL IMPL	CONTRACTS APPL'D	CONTRACTS IMPL	TOTAL IMPLEMENTED
JSC-09096	20	18	7	4	4	1	0	2	2	1	1	9
MSFC-SAT-SL-2-74	14	14	11	3	3	0	0	1	1	1	1	11
Lessons Learned - KSC	13	10	5	3	3	1	1	1	1	0	0	7
NASA HO-SL-3-74	14	12	11	6	6	4	3	0	0	0	0	10
S-II Stage	154	144	117	7	7	12	9	2	2	1	1	129
Skylab	37	31	3	5	5	4	4	1	1	1	1	10
NASA TM X-64574	29	2	1	22	9	9	5	0	0	0	0	12
MSC-00134	127	87	26	16	16	37	17	0	0	2	2	39
MSCM-8080	68	59	20	12	12	10	7	2	2	0	0	27
TOTALS	476	378	201	78	65	78	46	9	9	6	6	254

NOTES-In addition to the above the following additional items have been identified for further review:

MSCM 8080   7 lessons

All other documents   67 lessons

*APPL'D = Applied

IMPL. - Implemented

TABLE 6-2

SELECTED OPEN SAFETY CONCERNS

1. SSME Heat Exchanger Leakage
2. Ice From ET, Impact On Orbiter TPS
3. Post Separation Impact of Orbiter By ET
4. Use of SRB Nozzle Extension Separation Ordnance During OFT
5. SRB Ignition Overpressure On Space Shuttle During Lift-Off
6. Shuttle Potential Collision With The Tower On Lift-Off
7. Fire Potential In Orbiter Aft Fuselage On Launch Pad
8. Pre-Entry Thermal Conditioning Requirement For On-Orbit Contingency Aborts

CLOSED SAFETY CONCERNS

1. Access To SRB At Pad For Ordnance Checks
2. Impingment Of SRB Separation Rocket Motor Plume On Orbiter
3. Shuttle Vehicle POGO Suppression
4. Propellant Mixing At ET/Orbiter Umbilical During Separation
5. ET Venting Of Gaseous Hydrogen In-Flight
6. Jamming Of Payload Bay Doors In The Open Position
7. Deletion Of Drag Chute Subsystem
8. Smoke Sensor Provisions In The Orbiter Crew Cabin
9. Verification Of Crew Module Side And Airlock Hatch Pressure Integrity
10. OMS Pod And Wing Vent Mechanisms
11. Possible Forward Fuselage And Crew Module Collapse
12. Secondary Emergency Escape Provision
13. Orbiter Nose And Main Landing Gear Deployment
14. Venting Of LOX Tank Into ET Nose Cap
15. SRB Separation System Timing
16. Shuttle Carrier Aircraft/Orbiter Release Capability during ALT

ACCEPTED RISKS

1. On-Orbit Rescue During Early Orbital Flights
2. Manual Guidance Capability During Ascent
3. Emergency Drain System Provisions For ET
4. Smoke Sensor Provisions In The Orbiter Crew Cabin for ALT
5. Single Elevon Hydraulic Actuator
6. Bird Impact With Orbiter Windshield
7. Thermal Windshield Panes

TABLE 6-3

LEVEL II S,R&QA PRODUCTS (SELECTED)

1. ALT Mission Safety Assessment
2. Space Shuttle Safety Concerns
3. Space Transportation System Payload Safety Guidelines
4. Vehicle/Ground Systems Integrated Hazard Analysis
5. Main Propulsion Test Safety Plan
6. Main Propulsion Test Integrated Hazard Analysis
7. FMEA/CIL Status
8. Criteria And Standards Implementation Plans
9. SSME Heat Exchanger Pedigree Plan
10. Acceptance Data Package
11. Joint Surveys of NASA/Contractor Operations
12. Non-Destructive Evaluation
13. NSTL Quality Assurance Plan
14. Space Shuttle Personnel Motivation
15. Shuttle Orbiter Carrier Aircraft Service Bulletins
16. Shuttle/Spacelab Interface: Hazard Analysis and Payload Bay Fire Detection and Suppression
17. Space Shuttle SR&QA Plan
18. Interface Assurance Plans
19. ALT Safety Plan
20. OFT Safety Plan

FIGURE 6-1

SOLID ROCKET BOOSTER
FRACTURE CONTROL BOARD ORGANIZATION

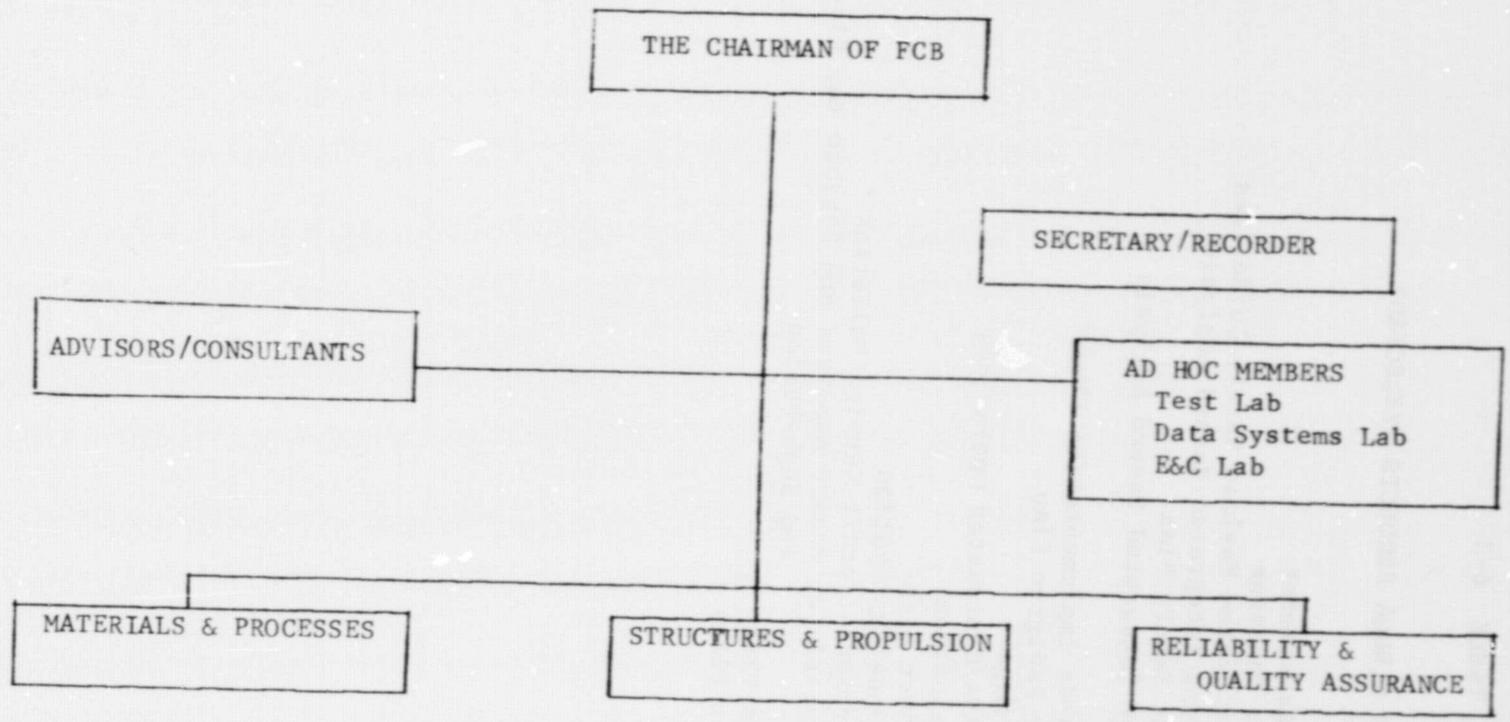
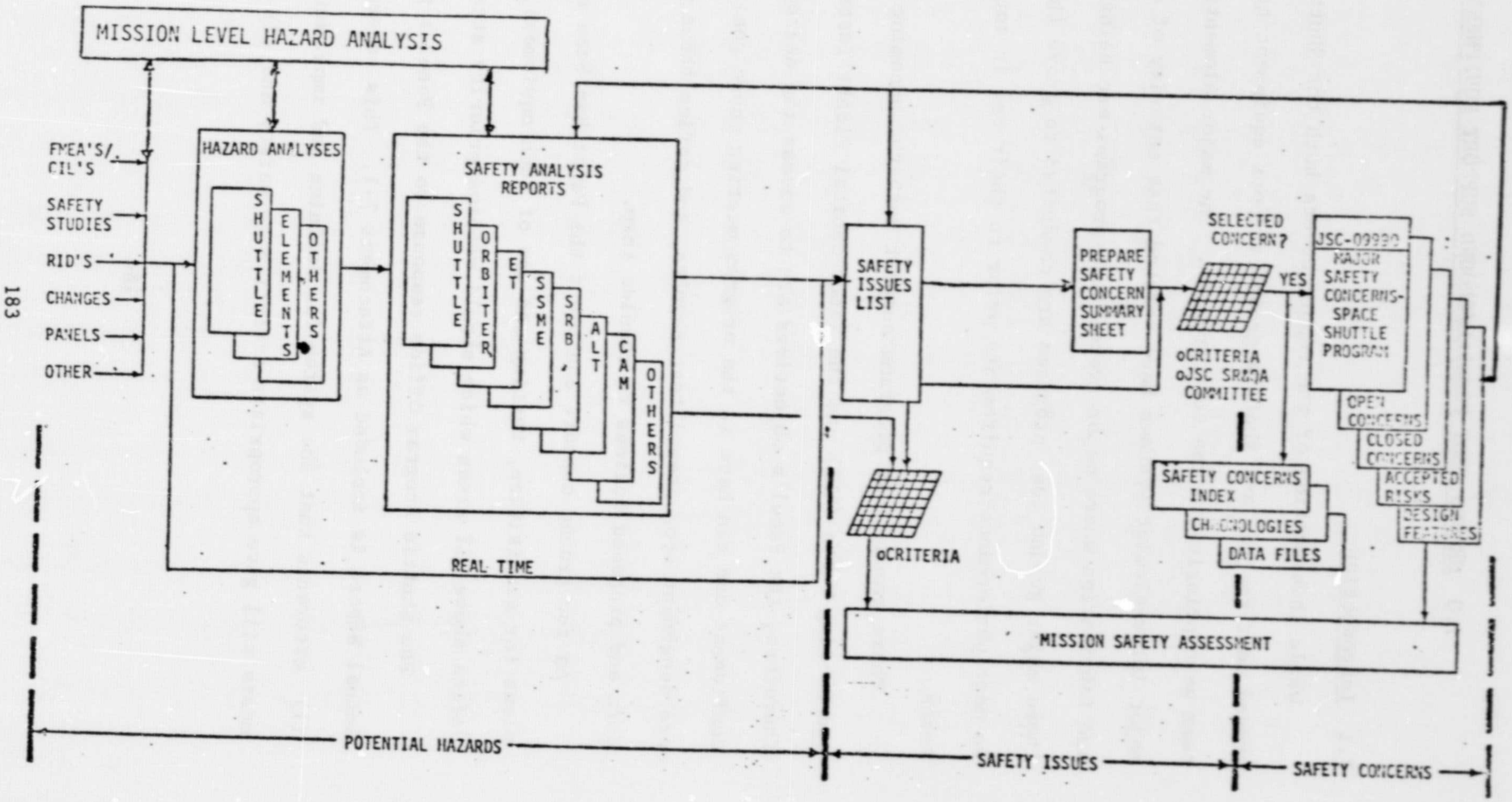


FIGURE 6-2

RISK ASSESSMENT PROCESS



7.0 GROUND TEST PROGRAM/GROUND SUPPORT EQUIPMENT

7.1 Introduction

While this section of the report covers both the Shuttle major ground test rpogram and Shuttle ground support equipment the task team gave priority to the test program. The major elements and major inter-element systems have reached that maturity of design and fabrication where major ground test programs are being initiated. These major ground test programs are conducted to prove the designs do meet performance requirements prior to their use in actual flight tests.

These ground test programs support both the upcoming Approach and Landing Tests (ALT) and the later Orbital Flight Tests (OFT). Therefore, the Panel's objectives are to assess the degree of confidence one can have in the program meeting those goals which are dependent upon ground test results, and define those areas of concern and proposed actions to resolve them.

As for ground support equipment the Panel has been reviewing the plans for acquisition, testing and use of such equipment, in order to define those ALT areas which should receive priority attention.

The Shuttle Program Office response to the Panel's previous Annual Report is included as Attachment 7-1. This covers two items: (1) assurance that the system for defining and implementing requirements will give appropriate attention to safety and (2) assurance

that planning is sufficient for ground testing to maximize confidence in safe development flights.

7.2 Shuttle Master Verification Plan (MVP)

The Shuttle MVP establishes the requirements and plans for verification of the Shuttle system for operational use, and provides the mechanism for program visibility and control. This plan consists of eleven volumes covering the following areas:

Volume I	General Approach and Guidelines
Volume II	Combined Element Verification Plan
Volume III thru VI	Element Verification Plans (Orbiter, SRB, ET, SSME)
Volume VII	Payload and Payload Carrier Verification (This is contained in Volume XIV, JSC 07700)
Volume VIII	Launch and Landing Site Verification Plan
Volume IX	Computer Systems and Software Verification Plan
Volume X	Master Flight Test Assignments Document
Volume XI	Shuttle Orbital Flight Test Requirements

The detail of this documentation and the planning that it represents is to assure the most effective utilization of program resources. The methods of verification include analysis and / or test. Thus decisions on the amount of hardware in a test program, the depth of the test program, the degree of element assembly at which tests are conducted are based on such factors as the sophistication of the design analysis,

the design maturity at the time of tests or analyses, the risk associated with degree of knowledge, the complexity of the test articles and the test program.

Phases of the verification program have been divided into (1) development, (2) certification, (3) element/system verification, (4) acceptance and checkout, and (5) ground system verification. This is then followed by the "proof of the pudding" in flight demonstration tests of the mature systems. The flight demonstration tests are in two phases: (1) the approach and landing test project dealing with the Orbiter and (2) the orbital flight test program using the entire Shuttle system of ground and flight equipments. After these phases the total Shuttle system is available for operations.

The following definitions are taken from the Master Verification Plan because they are very helpful in understanding the test plans.

a. <u>Development testing</u> is the program which verifies the design approach.

b. <u>Certification testing</u> is the program of qualification tests, major ground tests, and similar tests and analyses required to determine that the design meets the specified requirements. Major ground tests involve a combination of system elements, complex facilities, and large or expensive hardware segments. Qualification tests can and usually are conducted on components and assemblies within a single element, such as the external tank or the Orbiter.

c. Verification testing is the program to prove that the Shuttle system meets all designs, performance, and safety requirements.

d. Acceptance testing is the program that demonstrates that the actual part, component, subsystem, or system used in a Shuttle vehicle is capable of meeting performance requirements in such documents as the Contract End Item Specifications and so on.

e. Checkout testing is the program that verifies that the hardware/software for a specific mission will function within the prescribed flight limits both at subsystem and integrated vehicle levels.

f. Flight demonstration is the program that verifies the performance of the flight vehicles under predetermined flight conditions.

7.3 Review of the Test Program

The Panel in assessing the confidence level provided by the Shuttle test program focused on two areas: (1) the certification program for the first captive flight of Orbiter 101 mated with the 747 carrier aircraft and the certification program for the first free flight of Orbiter 101 in the ALT project, and (2) the certification program for the first manned orbital flight with an "all-up" Shuttle system.

Although the Space Shuttle ground tests are based to some extent on experience gained from such programs as Apollo, Skylab and ASTP and the unmanned programs, the uniqueness and resource constraints of this program levy different requirements and expectations. Therefore, areas of interest reviewed by the Panel included the following:

a. The test organizations at NASA Centers and their contractors with regard to responsibility and authority in the Shuttle program organization, their personnel numbers and skills, and the modes of management and communication.

b. Those tests considered mandatory prior to first flights and the rationale for this determination.

c. The logic behind decisionson additions, deletions, deferrals of the test requirements and the impact on hazards and risk acceptance.

d. The contingency plans to cope with "surprises" which usually occur during any test program.

e. Specific attention being paid by the program to critical items including those that have no redundancy, e.g., wing elevon actuators, thrust vector control actuators.

f. The system for assuring that the test requirements and procedures as well as hardware configuration control for a specific piece of hardware or software demonstrate the flight worthiness of that hardware or software.

g. The degree to which the test program and individual tests add up to an integrated test program and a reasonable basis for confidence in decisions on the flight worthiness of the Shuttle.

h. Retest plans that assure adequate deomonstration of vehicle integrity after replacements, modifications, repair, etc.

i. The system to assess the degree to which model testing, such as 1/4-scale model vibration and wind tunnel testing, will parallel the actual flight experience and therefore the difference that will have to be

considered in defining a safe flight test program.

j. Specific test situations such as:

(1) The ground rules for testing hardware so that it will see the full mission cycle environment rather than just its operating cycle environment.

(2) The rationale for using the structural ground test program as the basis for certifying the Orbiter 101 flight vehicle.

(3) The rigor of the testing to assure payload doors can be closed in orbit.

(4) The ground test program to determine control capabilities if a contingency situation develops where one or more APU's fail to operate.

(5) The program to accomplish some form of verification program for critical mechanisms to be sure that they can meet the conditions presented in long space soaks, long periods between checkout and use, and long periods of inactivity on the ground. Such critical mechanisms include the many door-control units on the Orbiter, and the flight control hardware.

(6) The rigor of the landing gear deployment test program to assure deployment during actual flights.

(7) Planned use of test teams and ground support equipment at factory, NASA Center, and specifically at KSC to assure that there is a maximum accumulation of experience and safe test operation.

7.4 Structural Proof Tests, Orbiter 101

Orbiter proof tests are to provide confidence in early phases of the flight test program by verifying integrity and rigging of control systems and selected doors. These tests assure that (1) control surface and door mechanisms and the associated structure have the strength and stiffness to withstand limit loads (i.e., maximum load expected during mission operation) without loss of operational capability, and (2) the hydraulic subsystem will provide the necessary stiffness to these surfaces to withstand aerodynamic flutter. The loads are those expected on the Orbiter 102 during an orbital mission. The test article is a flight vehicle except for the following items which would not be installed at that time: tailcone; thermal seals on the landing gear doors and rudder speed brake; elevon surface seals and TPS; crew seats and rails; pyrotechnic devices; and the use of simulated SSME's.

The testing will be performed after manufacturing checkout and before the ground vibration tests at the RI Palmdale assembly facility. The Orbiter 101 will be certified by analysis, and the vehicle will be placarded to 75% of limit load for all critical horizontal flight conditions. This does not include the thermal stress loads of Orbiter 102. The flight placards are being developed using ALT weights and configurations to derive ALT external loading and internal loading indicators to compare with the Orbiter 101 detail design and analysis. Because of the complexity and inherent costs required to separate thermal effects

from Orbiter 101 stress analysis the certification analysis will assume that thermal effects are present thus resulting in an additional structural margin.

The proof tests on the control surfaces of the 101 will develop design limit hinge moments with the actuation systems operating and the surfaces positioned at angles of deflection at which limit loads will occur. The landing gear doors will be proof loaded. The landing gear itself will be certified by component testing. The crew module will be pressure proof loaded to 17.7 psig which is 110% of design limit pressure. Modal surveys at frequencies of body bending and torsion, including torsion modes of the wing and fin, will be conducted on the Orbiter 101 after factory checkout to substantiate and update the dynamic math model by correlating analytical predictions with the measured test data. In addition there will be a calibration of the wind root strain gages during free flight to further substantiate the analyses. This will be done by comparing predicted conditions with flight data so that inflight loads will be verified before further explorations of the Orbiter flight boundaries.

To provide a baseline for evaluating the adequacy of this test approach, the related information from military and commercial wide-body test programs is summarized here:

a. The <u>L-1011</u> underwent a test program that included development component testing, proof loading to the limit load of control surfaces

C-3

and landing gear components, pressure proof testing of cabin to 60% of limit pressure. The completed stress analyses was accomplished prior to flight test. No primary structure proof loading or static test article loading was considered necessary. The vehicle was placarded to 80% of the limit load. Subsequent testing included a full airframe static and fatigue test.

b. The DC-10 designs underwent proof loading to limit load and this data was extrapolated to verify the analyses prior to first flight. In addition, the controls of the flight test aircraft were proof loaded and ground vibration tests were conducted prior to flight tests. No placards were imposed on the flight test.

c. The Boeing 747 experience prior to first flight is consistent with the DC-10. Full-scale static and fatigue articles were subsequently performed.

The primary structure will be fully certified prior to first vertical flight (OFT). The program calls for continuing testing in conjunction with analyses of the governing flight conditions. Thus, the static test article will be subjected to ultimate loads. Vibroacoustic tests will be completed on the aft fuselage test article. Vertical vibration tests and static firing of the main propulsion test article also remain to be done along with wind tunnel model testing. Component tests on such items as the window, side hatch, airlock seals and static and dynamic seals continues at this time. The Orbiter will not be placarded for vertical flight, but trajectory tailoring and adaptive flight control

will keep the loads well within prescribed limits.

7.5 Structural Test Article (Orbiter)

The Structural Test Article (STA) is of a production-type Orbiter in two sections, the airframe assembly and the crew module section, which will be subjected to static load testing in a special test series conducted by the Lockheed Company. During this major structural test, all major parts of the vehicle will be subjected to limit, fatigue, and ultimate loads to induce design level stresses and prove that all parts are capable of taking the expected loads safely. The airframe for STA uses substitute hardware for the nose and main landing gear, control surface actuators, crew module, OMS/RCS pods, and thermal panes. The crew module for STA uses substitute hardware for the windows and airlock tunnel.

Milestones for the STA program are as follows:

a. Delivery of the airframe to Palmdale test site during the first quarter of 1977.

b. Delivery of the crew module during the third quarter of 1977 to RI/Space Division.

c. Completion of the crew module tests in the Fall of 1978.

d. Completion of the airframe tests with a simulated crew module in the first quarter of 1979.

The four series of tests on the STA will cover influence coefficients such as modulus of elasticity, the limit loads, the fatigue loads and the ultimate load.

7.6 Payload Bay Doors

The following questions were asked during the Panel's examination of the payload bay door system: What testing is planned to assure payload bay doors can be closed in flight? What requirements are in the baseline for Extra Vehicular Activity (EVA) capability to overcome a problem which prevents door closure? What is the status of the development of this EVA capability? Responses to these questions are summarized below:

a. The planned test program provides for subsystem tests on latches and drive mechanisms; development tests on structural materials, lubrication, and mechanism latches; qualification tests simulating zero "g" and one "g" operations as well as on-orbit distortions with a 15-foot section of payload bay door and mating fixture. Details for this test are still being worked out.

b. The Payload bay door system is being designed so that for manual operation by a crewman in EVA in case there is an on-orbit problem with the door. Certain payload configurations and postulated failure modes will preclude access to the mechanisms. Thus JSC and RI/Space Division are currently assessing such challenges as the methods of ensuring that the doors can always be driven to an "open" position and the allowable number of latches "out" and still have a safe return. EVA routes and working envelopes required for a manual operation of the doors are under evaluation.

c. Airlock, EVA hardware, and EVA hardware servicing and recharge are now baselined. EVA provisions, such as translation aids, work stations, etc., have been developed and will be implemented in the near future. Handrails already designed for the remote manipulator system will provide additional EVA flexibility. The airlock locations and configurations that form a part of the total system have also been baselined at this time.

7.7 Ground Vibration Tests (GVT)

There are a number of ground vibration tests that have been discussed by the Panel: (1) Orbiter GVT, (2) Mated Orbiter/747, (3) Mated Vertical GVT including all flight elements of the Shuttle system. The overall ground vibration test program uses the building-block approach with tests progressing from one-fourth-scale models to the full-scale Shuttle system. Thus the initial verification testing of math models and analytical techniques will use the 1/4 models constructed of the same materials as the flight articles and made to the production drawings. These 1/4-scale models of the Orbiter, ET, SRB's should be ready before the end of 1976. After completion of the development testing phase at Rockwell they will be transferred to JSC for payload integration studies and operational support of the program.

7.7.1 Orbiter Horizontal Ground Vibration Test (HGVT)

The objectives of this test program are to determine the Orbiter modal characteristics for two support conditions: (1) Orbiter free

flight called a "soft" vibration test (Figure 7-1), and (2) Orbiter mated-type called a "rigid" vibration test (Figure 7-2). The soft or free-flight vibration test will also define the flight control frequency response characteristics relating to the deflection and slope at control system sensors for known input at the aerodynamic control surfaces. These tests are conducted on the Orbiter 101 or ALT Vehicle. These vibration tests are conducted following the structural mechanical proof load tests and are all conducted at the Palmdale facility. Rigid mount tests are to begin in late July 1976 and the soft mount tests are to begin in mid-August after completion of the rigid tests. Figure 7-3 shows the Palmdale checkout flow which includes these vibration tests.

7.7.2 Mated Orbiter/747 Ground Vibration Tests

The purpose of this type of test would be to assess and verify the adequacy of structural dynamic modeling and checkout structural response instrumentation. The need for such a test program is being examined by Rockwell and then recommendations will be brought to the Orbiter and Shuttle management for a decision.

7.7.3 Mated Vertical Ground Vibration Test Program (MGVT)

This test at MSFC is the culmination of the individual and scale model testing. As described to the Panel by the ground test subsystem managers there will be two major integrated vibration test phases: (1) a model test of the Orbiter/ET assembly on a soft suspension system

and (2) a modal test including the Orbiter, ET, SRB's to investigate conditions at lift-off, high-Q, and burnout. Initially, rigid-body modes will be determined to insure that the natural frequencies of the "soft" suspension system can be adequately accomodated. During these tests special precautions will be taken to prevent damage of any kind to the Orbiter and the ET since they will be refurbished and used for flight hardware. The SRB's will not be used as flight hardware.

7.8 Flight Control Hydraulic Laboratory (FCHL)

The objectives of tests conducted on the FCHL include: (1) verification of the hydraulic system, (2) integrated tests with the avionics development laboratory and hybrid computer for verification of end-to-end flight control system, (3) verification of the structural adequacy of the various control surface actuator mountings, (4) verification of the flight controls operations during real-time simulated mission segments, and (5) development of operational procedures to maintain a working hydraulic system. The test article as used in the FCHL is referred to as the Orbiter "iron bird", see Figure 7-4. It uses a qualifiable hydraulic system with simulated main engines, simulated aersurfaces and actuator mounts, but without landing gears. This program has been in progress since late in 1975 and will continue through early 1978. Current work will support the ALT project and later test work will support the first orbital manned test flights.

7.9 Crew Escape System Sled Test

The objectives of this test are to verify the capability and limits of the crew escape system for ALT and OFT including flare, landing, high-Q and High-G conditions. Current plans include one static and three dynamic tests to be conducted at the Holloman Air Force Base test track. Part of the work will validate the 6-degree-of-freedom computer analysis for adverse conditions which cannot be tested. An idea of the test itself and the items to be examined are shown in Figure 7-5.

7.10 Other Major Tests

A number of tests are covered under more specific chapter of this report, e.g., the Main Propulsion Test program. Others have not been examined to any degree by the Panel, e.g., vibroacoustic testing on the Orbiter aft fuselage. In addition to the so-called "major tests" the Panel expects to review the development and testing applied to some of the more critical hardware such as the Auxiliary Power Units, the fuel cells, thrust vector control and elevon actuators and others as deemed necessary.

7.11 Ground Support Equipment (GSE)

GSE is classified on the Shuttle program in accordance with the following functional groupings:

a. The servicing support equipment which supplies fluids and power to the flight hardware and associated GSE. This class includes equipment for supplying pressurization, purging, transferring fluids, etc.

b. Checkout and Test equipment which is used in all test and checkout operations. This class includes equipment that monitors, evaluates and stimulates hardware.

c. Handling and Transportation equipment which is required for the movement and support of flight hardware, including slings, stands, etc.

d. Auxiliary equipment which aligns, protects and calibrates flight hardware.

e. Umbilicals which are those items interfacing directly with the Shuttle elements to transfer electrical power, electronic signals, and fluids to and from the flight vehicle systems.

This area has been given lower priority by the Panel only because of the press of other Panel efforts. To some degree the Panel is in the process of scoping the task and defining the most effective approach to a continuing review of this area. The Panel began by reviewing the adequacy of management efforts to assure safe, cost-effective means of processing the Shuttle during all of its test and operational missions. The Panel has also reviewed the requirements and constraints placed on meeting the turnaround time and maintenance requirements, as well as the arrangements for alternate-field landings by the Orbiter.

Indicative of the examination the Panel expects to follow are the following:

a. How does KSC monitor the contractors for design and acquisition of ground support equipment that is to be used at KSC? What part does

JSC and MSFC play in the design, acquisition and use of GSE?

b. What are the critical elements within the GSE system?

c. What are the constraints on GSE development and procurement from the point of view of resources and schedule, and what are their impacts on the GSE program?

d. What are the plans for GSE to support the ALT project beginning with the preparation for the first flight in early 1977?

7.11.2 GSE Design Review Board

The group was established in early 1974 after the Orbiter 101 Preliminary Design Review conducted in February 1974. This Board is chaired by JSC personnel from the Orbiter Manufacturing and Test Office and from the Test Division of the Program Operations Office. Other members of the GSE Board are from RI/Space Division, the Orbiter contractors, KSC, MSFC with other members added as required from the three NASA Centers. Meetings of this Board are conducted monthly to assure that the designs are evaluated through a system of reviews similar to that for major elements of the Shuttle system (PRR's, PDR's, CDR's) before approval and authority to proceed are given. An example of this activity is the GSE BOard Review of April 7, 1976 in which 37 models of GSE were reviewed. The results were that 28 models were approved (7 for PRR, 1 for PRR/PDR, 9 for PDR, and 1 for PDR/CDR, and 10 for CDR), and two models were deleted or disapproved. The remaining models of GSE were deferred to the May Board for disposition. In addition, during this April meeting the Board handled fourteen (14) action items from previous meetings. In these

activities all personnel have an opportunity to write Review Item Dispositions (RID) where they feel there is an inadequacy. This is the same as the system used on the various elements of the Shuttle system.

7.11.2 GSE Design Review Status

Program studies are underway to assure: (1) common hypergolic servicing equipment to the optimum extent, (2) appropriate hydraulic servicing and test capability at KSC, (3) safe Solid Rocket Motor handling operations. The greatest numbers of GSE design reviews will occur in 1976. As expected, the evolving maturity of requirements has resulted in a slight increase of GSE models since July 1975. The planning for on-line maintenance and turnaround equipment and facilities for KSC is progressing satisfactorily. Maintenance planning for off-line Line Replaceable Units (LRU) has been postponed for the present.

7.12 Addendum

An updated summary showing the test, configuration, purpose and expected date of the test is shown in Table 7-1

ATTACHMENT 7-1

The program in assuring the cost effectiveness of its requirements for ground support equipment needs to assure safety receives appropriate attention.

Response: One method of minimizing GSE program cost has been to institute an agressive effort to assure that the maximum number of GSE end items is common to development test programs, the ALT program, etc., prior to OFT useage. Hazard analyses are being conducted on this equipment to assure adequate attention is being given to safety. Additionally, the Space Shuttle GSE design requirements have been reduced from the reliability level required to meet launch windows (Apollo) to a "fail-safe" requirement. This provides GSE which can sustain failure without loss of vehicle systems or loss of personnel capbability.

The program is in the period of defining the detailed requirements and plans for major development and flight testing. Plans for ground testing appear adequate. Safety-related testing should be monitored to insure it is carried through as planned. The interactions between the Orbiter, External Tank, and Solid Rocket Booster, including separation dynamics, are complex. Analyses based on ground testing should be thorough enough to maximize confidence in safe development flights.

Response: As noted by the ASAP, separation dynamics is a subject of continuous analysis backed up by ground test program. Wind tunnel tests of the ALT configuration (Orbiter/747) and the orbital configuration (Orbiter, ET, SRB) are being conducted to determine separation load dynamics. Actual ground tests of the separation hardware under various load conditions are planned. For ALT, safe separation loads using load cells in the actual flight separation system are being developed. Trajectory analysis of the ALT fly away and the SRB's and ET separations are being continually updated to investigate no recontact and safe separation. For ALT, approximately 4,000 computer runs of different test conditions were investigated in special McDonnell Douglas studies to assure safe operational separation margins. These types of analysis and testing will continue with the specific objective of assessing confidence in safe development flights.

TABLE 7-1

LG
MAY 76

SPACE SHUTTLE PROGRAM
GROUND TEST (1 OF 2)

TEST	CONFIGURATION	PURPOSE	TEST START
● GROUND VIBRATION TEST			
– HORIZONTAL SOFT MOUNT	OV-101 IN THE PRE-ALT CONFIGURATION	DETERMINE THE ORBITER FREE-FREE MODAL FREQ, MODE SHAPES AND DAMPING CHARACTERISTICS	AUG 76
– HORIZONTAL HARD MOUNT	OV-101 IN THE PRE-ALT CONFIGURATION	DETERMINE THE ORBITER MODAL FREQ, MODE SHAPES AND DAMPING CHARACTERISTICS - MOUNTED ON ET STRUTS	AUG 76
– 1/4 SCALE MODEL	1/4 SCALE REPLICA MODEL FOR ORB/ET/ AND SRB	MEASURE TRANSFER FUNCTIONS, AMPLITUDE - FREQ, MODAL DAMPING CHARACTERISTICS AND RIGID BODY MODES	NOV 76
– FULL SCALE MATED	ET/SRB/OV-101	VERIFY THE COUPLED DYNAMIC MATH MODEL OF THE MATED SHUTTLE CONFIGURATION	MAR 78
● ECLSS	BOILERPLATE TEST ARTICLE. COMPLETE ECLSS, PARTIAL AVIONICS, CREW EQUIPMENT	VERIFY ECLSS INTEGRATED OPS & PERFORM MANRATING OF ECLSS FOR FVF	MAR
● STRUCTURAL STATIC/FATIGUE (ORBITER)	AIRFRAME STRUCTURE INCLUDING ALL PRIMARY AND SELECTED SECONDARY STRUCTURE. GENERALLY, NO SYSTEMS	VERIFY STRUCTURAL INTEGRITY FOR: LIMIT & ULTIMATE LOADS AND 100 MISSION LIFE X SCATTER FACTOR OF 4	AUG 77
● STRUCTURAL TEST ARTICLE (ET)	LO_2 TANK, LH_2 TANK AND INTER TANK	VERIFY THE STRENGTH INTEGRITY OF THE PRIMARY LOAD CARRYING STRUCTURE	OCT 77

TABLE 7-1 (CONCLUDED)

LG
MAY 76

SPACE SHUTTLE PROGRAM
GROUND TEST (2 OF 2)

TEST	CONFIGURATION	PURPOSE	TESTS START
• MPTA	3 MAIN ENGINES + FLIGHT WEIGHT EXTERNAL TANK + FLIGHT WEIGHT AFT FUSELAGE, INTERFACE SECTION AND A BOILERPLATE MID/FWD FUSELAGE TRUSS STRUCTURE	VERIFY MPS PERFORMANCE AND COMPATIBILITY WITH INTERFACING ELEMENTS & SUBSYSTEM	DEC 77
• STATIC STRUCTURAL TEST (SRB)	SRB SHORT STACK CONFIGURATION, STRUCTURALLY FLIGHT TYPE VEHICLE WITH FOUR CENTER MOTOR SEGMENTS ELIMINATED	VERIFY STRUCTURAL INTEGRITY FOR CRITICAL DESIGN LIMIT & ULTIMATE LOADS AND THE NORMAL SERVICE LIFE	NOV 77
• FWD RCS STATIC FIRINGS	SHALL CONSIST OF STRUCTURE AND COMPONENTS FUNCTIONALLY CONFIGURED TO REPRESENT THE FLIGHT ARTICLE	DEMONSTRATE THE RCS PERFORMANCE AND COMPATIBILITY WITH INTERFACING ELEMENTS AND SUBSYSTEMS	NOV 77
• OMS/RCS STATIC FIRINGS	SHALL CONSIST OF FLIGHT WEIGHT PRIMARY & SECONDARY STRUCTURE, FLIGHT WEIGHT QUALIFIABLE COMPONENTS FUNCTIONALLY CONFIGURED TO REPRESENT THE FLIGHT ARTICLE	DEMONSTRATE OMS/RCS PERFORMANCE AND COMPATIBILITY WITH INTERFACING ELEMENTS AND SUBSYSTEMS	JAN 78
• VIBRO ACOUSTIC AFT FUS. NOW DELETED. ACOUSTIC DATA WILL BE OBTAINED IN MPTA	COMPLETE AFT FUSELAGE STRUCTURE, PARTIAL MIDBODY FUSELAGE AND A CLOSEOUT BULKHEAD, 100% INSTALLATION OF TPS & TCS	PROVIDE DATA: • TO ESTIMATE THE STRUCTURAL INTEGRITY • TO VERIFY VIBRATION ENVIRONMENTAL CRITERIA • TO VERIFY INTERNAL ACOUSTIC CRITERIA	SEP 78 (ORIGINAL PLAN)

FIGURE 7-1

HORIZONTAL GROUND VIBRATION TEST TEST ARTICLE DESCRIPTION

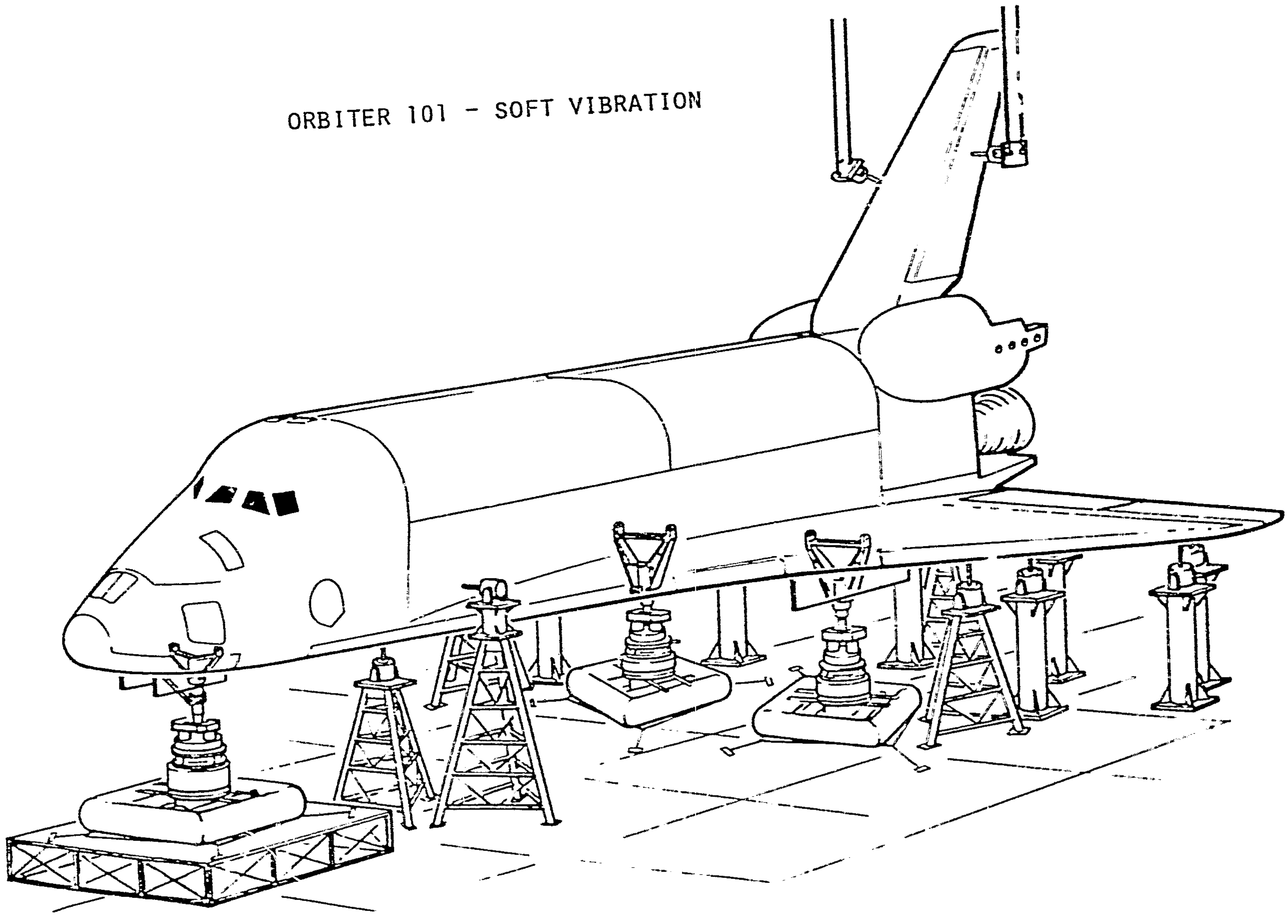


FIGURE 7-2

HORIZONTAL GROUND VIBRATION TEST
TEST ARTICLE DESCRIPTION

ORBITER 101 - RIGID VIBRATION

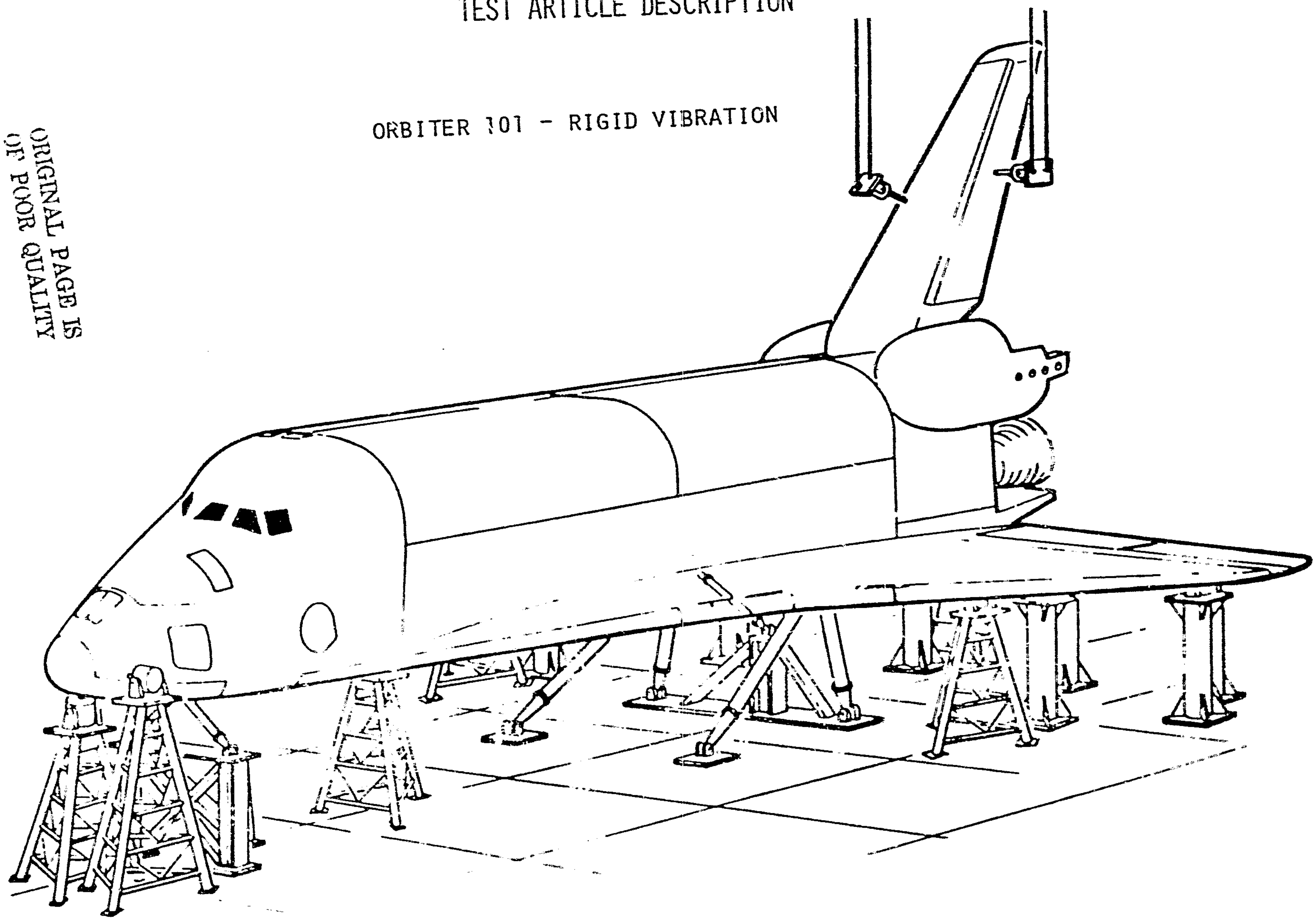


FIGURE 7-3

PALMDALE CHECKOUT FLOW AND CRITICAL PATH

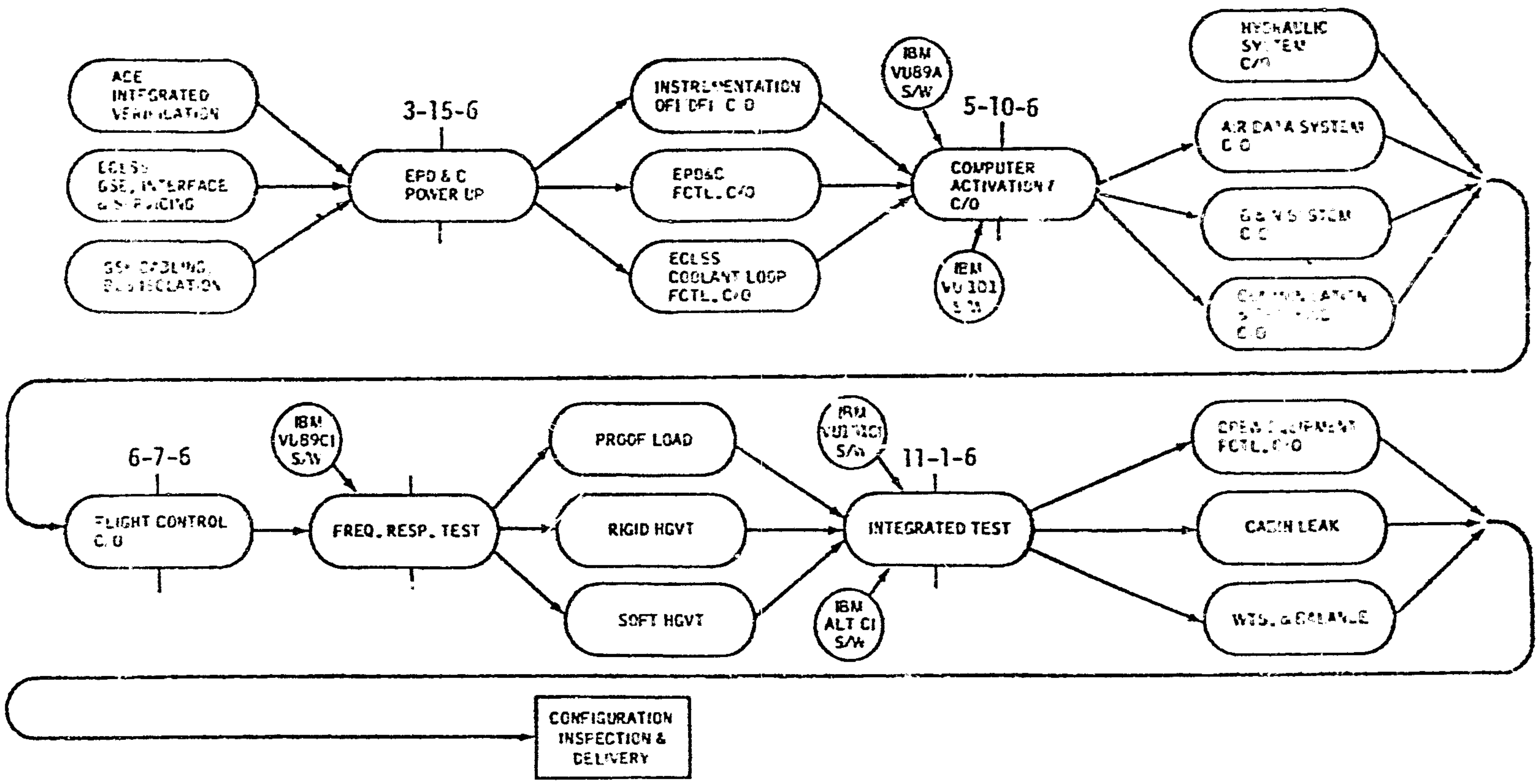
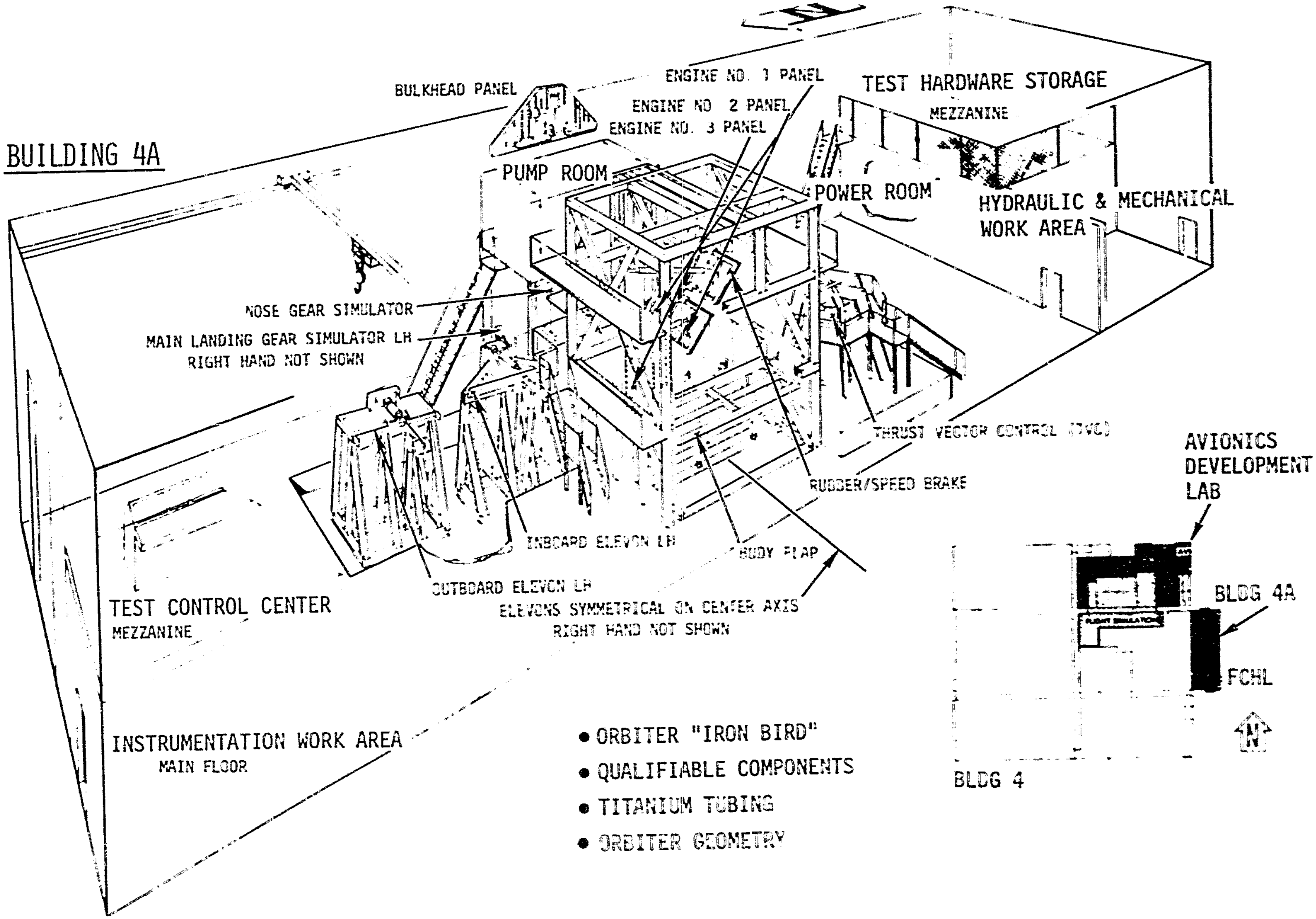


FIGURE 7-4

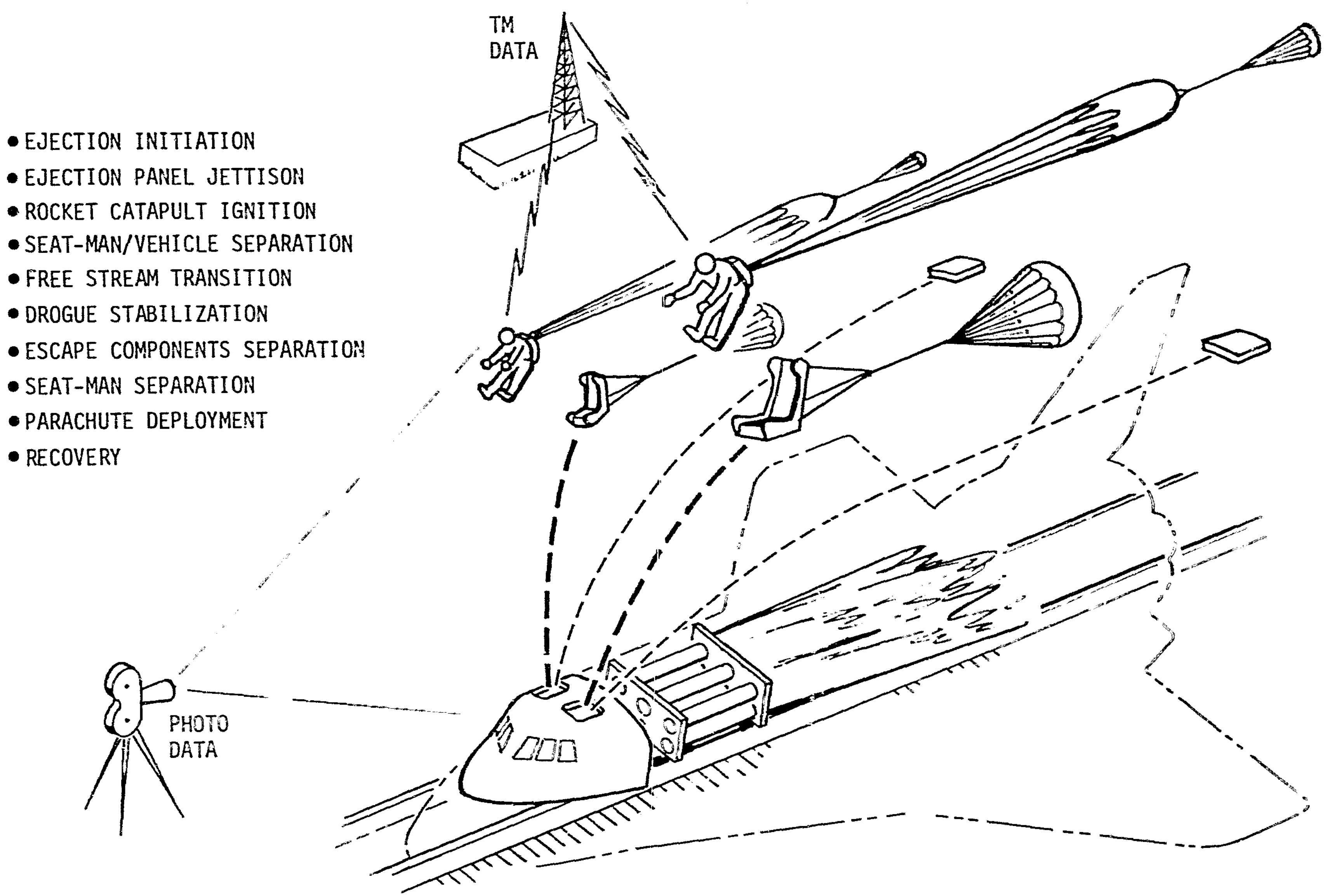
FLIGHT CONTROLS HYDRAULIC LABORATORY
TEST ARTICLE DESCRIPTION



- ORBITER "IRON BIRD"
- QUALIFIABLE COMPONENTS
- TITANIUM TUBING
- ORBITER GEOMETRY

FIGURE 7-5

ESCAPE SYSTEM SLED TEST



8.0 FLIGHT TEST PROGRAM

8.1 Introduction

Flight testing of aerospace vehicles possesses an inherent element of risk owing to the existence of many unknowns which cannot be resolved in analyses of the wind tunnels or other ground tests. The need for a flight test program of the Space Shuttle system is readily apparent given the unique configuration of the Orbiter and an assymetrical launch configuration which includes solid rocket boosters and the large external tank for the Orbiter's three rocket engines. Another new factor in the early flight tests is the use of the Boeing 747 airplane as a carrier vehicle for the Orbiter in the Orbiter/747 mated configuration, Figure 8-1.
The extent of the flight test program is not yet fully defined or baselined. Experience has shown that major ground tests combined with flight tests provides a synergistic approach to defining the expected operational characteristics and understanding the problems associated with shuttle missions. The previous section covered the ground test program and indicated the limitations of this test program. The additional data expected from the flight test program is described in this section.

The flight test program involves the verification of mature systems and thus is not to be considered a development program. Verification means the process that determines that the Shuttle meets

the design, performance, and safety requirements for flight. Specific requirements are chosen based on such criteria as (1) flight data is required to verify mission capabilities, (2) it is more effective to gather the data in-flight than by other methods, or (3) the data will answer questions remaining from the ground test program.

8.2 Shuttle Flight Demonstration Programs

The Panel is particularly interested in the process for:

a. Certification of the systems for the first captive and first free flights in the Approach and Landing Test Project (ALT). Certification includes both tests and analysis, i.e., design=requirements.

b. Certification of the systems for the first manned orbital flight with an all-up Shuttle System in the Orbital Flight Test Project (OFT).

The Panel is currently focusing on ALT and we will review OFT as that program matures.

To give the reader a sense of what has been accomplished and the work remaining here is a calendar of major milestones:

- Completed ALT Preliminary Design Review (PDR)	November 1974
- Completed OFT Preliminary Design Review (PDR)	March 1975
- Completed ALT Critical Design review (CDR)	April 1976

- Completed Delivery of Shuttle Training Aircraft (STA)	June/July 1976
- Orbiter 101 Rollout	September 1976
- Complete ALT Flight Software Verification	October 1976
- Complete First Approach and Landing Development Tests in the Flight Control Hydraulic Laboratory	December 1976
- Complete Design Certification Review (DCR) for First Captive Flight and First Free Flight	December 1976
- Complete the Flight Readiness Review (FRR) for the First Captive Flight	February 1977
- Conduct First Captive Flight (unmanned)	March 1977
- Conduct First Captive Flight (manned)	June 1977
- Complete FRR for First Free Flight (ALT)	July 1977
- Conduct First Free Flight (ALT)	July 1977
- Complete OFT Critical Design Review	August 1977
- Conduct First Manned Orbital Flight Test	March 1979

8.2.1 ALT Project

The ALT project together with analysis and wind-tunnel and ground tests is intended to evaluate the Orbiter's stability and control. In conjunction with subsystem operation, it will verify the vehicle's ability to meet airworthiness and performance requirements dictated by the terminal phases of the operational and ferry

missions. In this case "terminal-flight phase" consists of all those activities conducted from an altitude of about 25,000 feet to roll-out. This project thus includes such areas as vehicle ground tests before the first drop test, preliminary flight evaluation, flying quality investigation subsystem verification, and demonstration of the unpowered terminal-flight phase.

The Orbiter 101 used in the ALT project generally will not include subsystems required only for space operations but will employ simulations of equipment as necessary to demonstrate the effects of such systems and payloads on approach and landing performance.

The Panel structures its efforts on the ALT project so it can provide:

a. A periodic report on the status of preparation for ALT.

b. A flight readiness assessment which the Administrator uses in his personal flight readiness review.

The Panel therefore raises such questions in its review as:

a. What are the OFT risks that would have to be accepted if there were no ALT project?

b. What are the risks involved in the ALT?

c. How does the Shuttle Training Aircraft training program and other ground based programs minimize ALT risks?

d. What are the abort mode capabilities for the mated configuration and for the individual 747 and Orbiter?

e. Is the extent of the Development Flight Instrumentation for ALT sufficient to allow for anticipation of developing problems as well as for real-time problem resolution?

f. What is the extent of "sensitivity analyses" conducted to determine the effect of input parameter perturbations from external and internal sources, and what are the results to date?

g. What are the data collection and data reduction processes and problems?

h. What is the definition of piloted and automatic trajectories during free-flight and how they are matched? What are the provisions for auto-to-manual transition or vice-versa?

i. What is the process for developing the ALT Mission Safety Assessment Report?

As an example of the dialogue with the Program their response to the Panel's comments and questions in last year's report are included as Attachment 8-1. It covers four areas: (1) free fall deployment of the landing gear; (2) ALT risks vs benefits; (3) the role of man-in-the-loop; and (4) contingency analyses and range safety.

8.2.2 Orbital Flight Test Project (OFT)

OFT will demonstrate the total Shuttle system's flight-worthiness and capability to conduct actual missions. This project extends the Orbiter flight envelope from the ALT limits to include mated ascent with the ET and SRB's and then separation from them, orbital insertion and on-orbit operations of the Orbiter and then its entry and landing. This project also is to verify the ability to recover the SRB's. In summary the project will demonstrate the compatibility of the Shuttle elements for the phases of pre-mission operations, mission operations, and post mission operations.

The current OFT project contains a series of six-manned flights.

8.3 Observations on Approach and Landing Test (ALT)

As stated in briefings given to the Panel and as written in Shuttle program documents (such as JSC 08943, "Flight Test Requirements - Orbiter Approach and Landing"),"the data and experience to be gained from the Approach and Landing Test (ALT) program justify performing the tests. No single test requirement justifies the effort; however, the aggregate return from the several tests does justify the test program".

Based on earlier discussions, prior briefings, and individual Panel member experience, it was assumed that the ALT program was a mandatory part of the overall Space Shuttle Master Verification Plan. However, the most current Panel/JSC discussions indicate that the ALT

project is not a required precursor for the first manned orbital flight (OFT), but rather a very worthwhile program to be used in conjunction with analyses, wind tunnel tests and ground tests to evaluate, during approach and landing, the Orbiter's structural, avionics, electrical, hydraulic, environmental, flight control, and landing subsystems. This observation is reinforced by a comment in one of the discussions that the crew for OFT did not have to have ALT flight experience.

8.3.1 ALT Management

The organization that manages the various elements that make up the ALT and OFT projects within the Shuttle program are worth noting for several reasons: (1) the Panel cannot verify all decisions but must depend on the adequacy of the basic management system, (2) risk management decisions depend on the organization(s) involved in the decision making process, and (3) the review system and its ability to prevent things from "falling through the crack" is related to definition of organization responsibilties. The organization is outlined in Figures 8-2 and 8-3. Changes to this organization arrangement should be expected as the ALT and OFT projects evolve and there is a better understanding of the work to be done and where the emphasis should be placed. The remarks that follow identify the more salient details.

The Johnson Space Center Flight Operations Directorate has over-

all responsibility for planning and conducting the ALT project so it satisfies test objectives and test requirements. The development of an ALT program and technical management system was the work of the Orbiter Atmospheric Flight Test Office at JSC within the Flight Operations Directorate. While the Orbital Flight Test (OFT) program detailed plans and organization are being developed by the Operations Integration Office at JSC which reports directly to the Space Shuttle Program Manager.

Management reviews are of two types: (1) those dealing with the Orbiter 101 vehicle, and (2) those dealing with the ALT program itself. These reviews are similar in type to those described for other elements of the Shuttle program. An example of the reviews is the Orbiter 101 Configuration Review (Phase 1) conducted in February and March 1976 to assess whether Orbiter 101 subsystems and GSE were ready for the subsystem test phase. In the process a list of constraints was established which were to be worked off before or during the test program. Another milestone review is the Approach and Landing Test Critical Design Review (CDR) in March and April 1976. It gives management another opportunity to review in detail the test and test support operations to be performed, the facilities and equipment to be used, and the management and working relationships of the test organizations conducting the ALT project. This

CDR covered the activation of the ALT capability, the conduct of the test program, and the deactivation of the ALT capability. The Review teams for the CDR included KSC, JSC, DFRC, Rockwell, and Boeing personnel. There was a similar CDR for the Shuttle Carrier Aircraft which was conducted during the April-May 1976 time period to assure that the detailed production design meets the specified requirements.

The ALT baseline has been defined as to the number of flights, the configuration of the Orbiter (i.e., tail-cone on or off) for specific flights, data requirements and on-board computer capabilities, etc. These areas are covered in more detail in later sections of this report. NASA management at every level, from first-line supervisors to the Headquarters' Management have been and continue to give the ALT program a great deal of attention to assure that this most significant area has the decision-making system it needs.

8.3.2 Palmdale to DRFC

The Orbiter 101 can be moved the thrity miles from the Palmdale Assembly plant to the DFRC either by a ground transportation system or by a ferry flight using the 747 carrier aircraft. A number of factors were considered: (1) legal aspects of overland movement on and off of established roadways, (2) safety aspects of accomplishing

a series of taxi tests at the Palmdale facility prior to actual ferry operation, (3) ability to abort the first flight, (4) relative costs involved in the move one way or the other, (5) and probability of Orbiter or 747 damage either way. The overland transportation of the Orbiter has been baselined. This decision was based to a large degree on the operational questions dealing with mated-taxi tests and flight out of Palmdale versus taxi and first flight at DFRC with regard to safety margins.

The configuration for the first flight, if made from Palmdale is:

- Orbiter 150,000 pounds
- Carrier 60,000 pounds of fuel using flaps at 20°
- Mated 550,000 pounds and a velocity of rotation (V_r) of 136 knots

The Palmdale runway is 12,000 feet in length. The V_r = 136 knots would be reached at about 3650 feet, lift-off at 147 knots would occur at about 4600 feet and the following 17 seconds at the lift-off speed would be available for abort (i.e., from 4,600 feet to 8,850 feet along the runway). The remainder of the runway, from 8,850 feet to the 12,000 foot mark would be required to halt the mated Orbiter/747 vehicle. At the DFRC/Edwards AFB runway capability on the concrete is 15,000 feet and over 7½ miles on the lake bed. Thus there is greater flexibility available at DFRC to handle variations

in take off and extended taxi tests. In fact there is a capability to go slightly beyond taxi tests to actual short-term very low altitude tests.

8.3.3 ALT Baseline

The ALT has for some time consisted of the following components:

- Test of modified 747 aircraft by Boeing and DFRC
- Mated 747/Orbiter taxi tests
- Mated flight tests
- Free flight tests after mated take off and flight

A typical tailcone off free-flight ALT profile is shown in Figure 8-4.

Various NASA and contractor organizations associated with the flight test program have been investigating the many aspects of ALT to maximize the information return versus the flight capabilities of the 747/Orbiter system. Studies concern such areas as 747-Orbiter separation altitudes and attitudes, 747 buffet problems associated with mated flight, separation velocities, effects of variations between wind-tunnel testing and actual flight aerodynamic performance, crew safety, data and data reduction requirements, crew training and the final approach trajectory from preflare to landing.

A major item affecting the implementation of the ALT baseline is the impact on the mated vehicle's flight performance and the associated buffet characteristics if you fly the Orbiter without a tailcone. All other concerns are of second order importance in defining the mated and free-flight program.

The mated Orbiter/747 will take off with a fixed Orbiter incidence angle of 4.5 to 7.5 degrees. The weight will probably be between 150,000 and 170,000 pounds. The mated vehicle will climb to a ceiling altitude (maximum climb thrust) and cruise for approximately 15 minutes. A special rated thrust will then be used to achieve a higher ceiling altitude at 200 feet per minute. The time duration of this special thrust rating is 10 minutes. Once the ceiling altitude is achieved, a descent maneuver will be initiated to accelerate the mated vehicle to the desired launch airspeed in an equilibrium glide condition. This will be based on derivatives of pitch rate, flight path angle, sum of aerodynamic and thrust pitching moments all equal to zero. The acceleration is performed after the thrust is reduced from the special rated thrust to the maximum continuous thrust level. The Orbiter elevon is to be positioned to a predetermined value to achieve a relative normal load factor of 0.75g and an Orbiter pitch acceleration of approximately 4.0 degrees/second^2. During the mated descent phase, the

747 will be configured to increase drag in order to enhance separation. Separation is to occur as the launch airspeed and equilibrium glide conditions are achieved. The typical ALT baseline is shown in Figure 8-5.

The baseline ALT program, taking into account the many studies conducted, is:

a. Reduction in the 747 tests by Boeing.

b. Mated tests with 747 and Orbiter with tail-cone on.
Taxi tests plus 6 flights with inert Orbiter.
Taxi tests plus 5 flights with active Orbiter.

c. Free flight tests conducted with tail-cone on.
4 flights to land on the lakebed runway.
1 flight to land on the concrete runway.

d. Free flights with tail-cone off if possible. This decision will be based on data obtained in all of the previous flights along with wind tunnel tests and a detailed analysis. Currently the program calls for 3 flights to land on the lakebed runway. This would be preceded by a mated active flight test with tailcone off. The number of flights and their content is under review.

The tailcone refers to the aerodynamic conical shaped body attached to the Orbiter to reduce drag and reduce buffeting of the 747 tail sections in particular due to carrying the Orbiter piggy-back. The extent of the buffeting with tail-cone off would be severe tests and analyses indicate that. The buffeting can se-

verely reduce the structural life of the 747 tail particularly the aft body structure and vertical tail section. It can also prevent the crew from achieving necessary proficiency during the critical release and separation maneuver period. Finally it can generate a general fatiguing vibration during all portions of the mated flight. Uncertainties exist in scaling buffet loads from model scale to full scale because there is no real methodology to accomplish such scaling; therefore, additional critical areas could be affected. If buffet loads were in error by a factor of two, the resulting fatigue life calculations might be in error by a factor of as much as ten. Considering such uncertainties the Shuttle program has used a conservative approach to defining the expected fatigue life values.

The 1.4 hours of a single ALT test mission approaches the age life of the aft body section at the tail. The vertical tail section computed life is about 10 hours. These times can be increased through several means including the use of an 11.7 degree Body Flap Up and beefing-up the structure in the body and fin areas. This is being done to increase the lifetime to approximately 50 hours before the first crack appears. While flying the Orbiter with the tail-cone on relieves the buffeting problem, the aerodynamic performance of the Orbiter during free flight is not exactly equal to that which would be experienced with the true Orbiter configuration. This has also been examined and it has been

suggested that the Orbiter with tail-cone-on can be made to behave more like the mission configured Orbiter by deploying the rudder speed brakes. This does appear though to cause a some degree of loss in pitch control.

For the reader to follow the evolution of the program it is worthwhile for the reader to understand the terms used (Figure 8-6), the requirements for unpowered landing (Figure 8-7), unpowered flight constraints (Figure 8-8), and the Autoland logic (Figure 8-9).

8.3.4 Deployment of Orbiter Landing Gear

The Panel was interested in the basis for confidence in the ability of the gear to deploy and lock into place prior to touch-down and the aerodynamic affect of having the gear deployed during mated flight.

The free-fall deployment system has been examined not only by the engineering and test personnel but also by the highest levels of Shuttle management to assure that it will operate properly. As a result of this review the free-fall mechanism has been augmented by additional spring devices. Once the doors are open and the gear are partially deployed the combination of initial downward momentum, aerodynamic forces and the mass of the gear appear sufficient to fully deploy and lock the gear. Hydraulic actuator deployment force is also available. There will, of course, be a detailed

and thorough test program to provide further confidence in the adequacy of the system. The specification for the deployment window of time during which the gear must safely be lowered calls for a maximum of 10 seconds, but at this time analysis indicates that it will take about seven seconds. The gear retraction is accomplished only on the ground and cannot be done in flight.

It is planned that during one of the mated (captive) flights that the Orbiter landing gear will be deployed during landing rollout. This will permit information to be obtained on the aerodynamic characteristics of the Orbiter as it will appear in actual flight just prior to touchdown. Current indications are that this will not cause undue buffeting of the 747 carrier aircraft.

Further discussions of this area of concern are found in the "Risk Management" section of this report.

8.3.5 Orbiter/747 Separation

The separation sequence, when free flights begin, is perhaps one of the more significant areas of concern. The overriding requirement is that there be no recontact between the vehicles once separation begins. The degree to which analysis can define the envelope of separation is dependent on the accuracy of wind tunnel data and the inherent aerodynamic uncertainties therein.

The variables associated with this maneuver are:

(a) Orbiter/747 aerodynamic uncertainties.

(b) Orbiter incidence angle (currently $6^{o} \pm 1.5^{o}$).

(c) Orbiter body flap, speed brakes, elevon positions and capabilities.

(d) Separation "g" requirements.

(e) Flight control system command mode and rates.

(f) 747 spoilers, thrust position and capabilities.

(g) Mated altitude and speed.

In order to obtain a greater degree of understanding of the ALT design and performance characteristics as well as the risks involved activity continues in the following areas: (1) Testing, particularly wind tunnel work, (2) analysis, particularly to uncover areas that can be improved, (3) simulations and pilot training, (4) refinements of flight test data and instrumentation requirements to get the most data for the effort involved.

Figure 8-10 shows pictorially the clearance requirements for separation. The design goal and maximum allowable motion are both shown.

Simulations have been conducted many times on the ALT flights. These have been run by the "Separation and Pilot Operations Group" at Rockwell and at least five pilots from the NASA/JSC astronaut corps.

Results from these simulations indicated that there would be no vortex clearance problems for either the tailcone on or off. The effect of Orbiter weight and c.g. location did not have a significant affect on the separation or Orbiter performance. While an increased launch speed from 260 to 280 Keas did not significantly affect the separation trajectory, it does appear to improve performance for the final approach condition.

The tailcone on configuration was noted to have a beneficial effect from two aspects: (1) Orbiter/747 separation was better with a near vertical deplacement of the Orbiter relative to the 747 for the first few seconds, and (2) Orbiter ALT final approach conditions were significantly better than for the tailcone off configuration.

The effect of wind/shear, discrete gust, and random turbulence were within the baseline capability and did not present a separation problem or appreciably affect the Orbiter handling qualities. As a result of the simulations and analyses to date, the following separation and post separation conditions have been established:

(a) Separation Initial Condition

1. Normal relative load factor = 0.75g.
2. Orbiter pitch acceleration = 4.0 degrees per sec^2.
3. Launch airspeed = 260 Keas.

4. Equilibrium glide.

(b) Post Separation Conditions for Orbiter

1. Autotrim enabled at separation.

2. Post separation (free-flight) FCS surface limits will be selected at separation.

3. Maintain 2^{o}/sec pitch rate command for 3 seconds followed by a 2 second stabilization period.

4. Maneuver to ALT interface.

(c) Post Separation Conditions for 747

1. Initiate 747 evasive maneuver (bank) at t_{sep} + 5.0 seconds 747 wheel command of 50^{o} for 10 seconds with 747 FCS in autopilot mode.

2. There is a possibility that a recommendation will be made to use a bank maneuver of 30^{o} at approximately 10^{o}/sec. with the 747 FCS in a manual direct mode.

8.3.6 Crew Emergency Egress

Emergency egress during ALT means both escape from the 747 and escape from the Orbiter. The system for the Orbiter 101 vehicle consists of ejection seats traveling on rails with overhead ejection through doors cut in the top of the cabin. The emergency system for the crew of the 747 has been somewhat more difficult to baseline. After technical studies and management discussions it was determined that there should be a specific escape system placed into the 747. The design selected is a tunnel going from the flight

deck where the two crewmen are located to a point on the lower left side of the 747 fuselage, Figure 8-11 The lower end of the tunnel is opened by a pyrotechnic severance system that cuts the fuselage thereby permitting the crew to exit from the flight deck to the outside. At the same time as the fuselage is cut it is necessary to equalize the pressure between the cabin and the atmosphere by blowing out (or in) windows and a portion of the lower right side skin. The Teledyne-McCormick-Self Company has been selected to provide this egress system. Tests and analyses will be conducted on this arrangement to assure the smooth cutting of the metal skin and the proper rate of decompression. Training, of course, will be required to assure the crew can and knows exactly how best to escape if the need arises. The system will be designed for the 20,000 feet to 24,000 feet range of altitudes.

The Orbiter ejection seat is a "zero-zero" seat. The first static test of the Orbiter 101 ejection seat is to take place at the Holloman AFB High Speed Test Track during January 1977. Hatch jettison tests would begin in March 1977. The first manned ALT flight (captive or mated) is set for May 1977. Testing of the overhead hatch has been in process for some time and qualification testing on the energy transfer subsystem is essentially complete. Two anomalies were noted regarding the operation of the

hatch: (1) detonation velocity indication was lost during one test but the output of the charge was satisfactory, and (2) one 0.5 second time delay time-data was lost during testing. Neither of these appear significant and their resolution is expected soon.

The Critical Design Review on the outer panel severance system was completed. Qualification of this sytem is to start in May 1976. During the development testing of the inner panel severance system the following anomalies were noted: (1) failure of the panel to sever, and (2) gas leakage into the crew compartment. The inner panel failure was due to using the wrong material in the subscale test panels. A new test using proper materials is in the works now. The gas leakage into the crew compartment was due to expending tube rupture during overload or hot temperature nominal load tests. Apparently there is small margin between severing the panel with an 80% charge and containing the gas using a 115% charge. Before start of the qualification program this problem will have to be resolved. See Figure 8-12.

8.3.7 Additional Notes of Interest

8.3.7.1

The Gulfstream Shuttle Training Aircraft, as an inflight simulator, will provide some important data for the first free-flight

of the Orbiter. However, the fidelity of the simulator is based on the wind tunnel data and it will be as good as the interpretation of the data by aerodynamicists. The USAF and NASA have frequently seen significant differences between wind tunnel data and flight data.

8.3.7.2

The 747 flight test team is in a monitor role with the 747 crew in control of "going ahead" and the Orbiter crew in control of the decision on separation or "abort" of the free-flight mission. There is to be no overlap of authority and the communications system is to in no way "shut off or overlap" the flight crews.

8.3.7.3

The factors which need co be accommodated in planning the Approach and Landing Test Project include (1) possibility of limited or no capability to carry and launch a tailcone-off Orbiter from the 747, (2) definition of the flight performance margins afforded by a tailcone-on first free flight, and (3) need for exercising ALT curtailment options for unanticipated contingencies, cost constraints, schedule constraints, etc.

8.3.7.4

A preliminary ALT manned Orbiter contingency operation plan has

been produced. The evolution and implementation of this plan will be followed by the Panel. The purpose of the document is to describe the immediate actions and responsibilities to be used in the event of a catastrophic situation when the Orbiter is manned during the ALT operations. Procedures for catastrophic events occurring at other times will be described in appropriate documents for both the ground crew and the 747 teams.

8.4 Manned Orbital Flight Test Program

At this time the OFT guidelines are that the OFT will consist of six flights. The first flight will be manned and conducted with greater than nominal performance margings. The performance envelope will be gradually expanded staying within the operational design capabilities of the Shuttle vehicle.

Its crew will consist of two men on flights one through four with an option of four men on flights five and six. The data return requirements are to be principally for engineering information. Scientific data will be obtained on a non-interference basis. DFI will be flown on all six flights. Candidate payloads will be used whenever possible, consistent with the availability and cost effectiveness of the payload versus the mission to be flown.

The major areas of planning include the following:

(a) Definition of orbital flight test plans.

(b) Development of operating concepts and requirements.

(c) Development of training requirements and implementation of trainers and simulators.

(d) Development and implementation of control center and network requirements and capabilities.

(e) Development of flight planning capability.

(f) Development of the launch and landing ground operations and interface with flight control.

One problem noted during our JSC discussions was the use of "add-on" units containing large quantities of liquid ammonia to be used as part of a cooling system for DFI equipment. These add-ons were located in the Payload bay but the vent system was not discussed at that time, nor were the steps that would prevent corrosion due to the ammonia fumes. This area will be followed by the Panel in future reviews.

8.5 Addendum

The first flight of the modified shuttle carrier aircraft is scheduled for the end of November or early December 1976. The aircraft design gross weights have been stated as follows:

Taxi	778,000 pounds
Takeoff	775,000 pounds
Landing	565,000 pounds.

Most of the modifications made to this aircraft are shown in Figs 8-13,14.

The Orbiter flare techniques are still under study to assure that the selected mode will be most effective in achieving the objectives of the ALT project. Float time requirements, the time interval available to the pilot during which he can adequately perceive sink rate and adjust it to arrive at an acceptable value for touchdown, should fall near the following:

a. A minimum time of seven (7) seconds and an optimum of 11 to 14 seconds.

b. For precision landings the last three (3) seconds should be flown at essentially constant altitude.

The need to have a least one free-flight landing on the concrete runway at DFRC is predicated on the difference between lakebed surface and conrete runway surface on landing gear-wheel-brake effects. The difference in coefficient of friction and other surface effects on the gear dynamics and anti-skid tuning are sufficient to make a conrete runway landing worthwhile.

Landing gear test problems have occurred during the checkout and test work being conducted at Palmdale Facility when an uplock hook failed. In addition they have found that the other uplock hooks had cracks. Plans are for an investigation by RI/Space Division and NASA/JSC to be done in two phases: Phase I for Orbiter 101 and Phase II for Orbiter 102 and subs. Ground rules being utilized are:

a. Review all criticality I single point mechanical failures that can cause loss of vehicle or crew.

b. Both sides of the loaded interface will be reviewed for design criteria consistency, for example, the actuator load rating versus mechanical joint design load used in the analysis.

c. Phase I and II refers to hardware first usage and not loads.

ATTACHMENT 8-1

Free fall deployment of landing gear may introduce safety problems. Therefore, the use of a positive system for rapid extension of landing gear should be considered.

Response: The basic design of the landing gear system is conservative with four forces acting to deploy the gear, the up-lock actuator, the weight of the gear, the strut actuator, and the locking spring bungee.

The concern about positive rapid extension has been recognized. Plans to utilize pre-loaded springs as additional forces to pop the doors and speed the gear deployment are being investigated.

A comprehensive test program using both a nose gear and main gear simulators with flight type gear and door hardware with hdraulic systems and electrical systems in the OV 101 configuration will be tested at Rockwell International. Loads simulating aerodynamic forces obtained from wind tunnel tests, will be applied to the gear and door assemblies during these tests. Wind tunnel tests of a 1/3 scale model will be conducted for aero loads with gear retracted and deployed as well as tests on a 0.04% model for loads at incremental positions.

Additional studies are continuing on the usefulness of extending the landing gear during a 747 captive flight.

More information is needed on the risks of Approach and Landing Testing in comparison with the value of information which would be obtained in such flights.

Response: The Approach and Landing Test (ALT) program objectives are as follows:

1. Verify an Orbiter pilot guided approach and landing capability.

2. Demonstrate an Orbiter subsonic auto TAEM/auto land capability.

3. Verify Orbiter subsonic airworthiness, integrated system operations and selected subsystems operation for first orbital flight.

4. Demonstrate Orbiter capability to safely approach and land in various center of gravity configurations.

These important objectives can be accomplished with acceptable risks.

Extensive analysis, wind tunnel testing, and man-in-the-loop simulations have demonstrated the safety of the ALT test flights. A comprehensive matrix of separation configuration and aerodynamic parameter variations has been analyzed. There have been approximately 2,200 hours of wind tunnel testing, 200 piloted simulation runs, and 3,000 12 degree of freedom separation trajectories completed. Numerous variations in configuration, control modes, aerodynamic coefficients, altitude, velocity, and flight path angle have been studies. Safe, acceptable separations are produced within a large envelope of conditions.

The top launch concept has been employed successfully in the part. Programs employing the top launch concept include the British Mayo Composite Aircraft, the German Mistel, and the French Leduc.

The ALT program decreases overall Space Shuttle Program risk. The Orbiter is a highly sophisticated combination aircraft/spacecraft with a digital, fly-by-wire, flight control system. ALT provides for the detection and correction of problems in the important approach and landing regime prior to the orbital flight tests. The ALT tests will essentially verify the aircraft capabilities of the combination aircraft/spacecraft Orbiter.

The remaining issues being examined relate to the launch altitude of the Orbiter from the 747 and the launch configuration of the Orbiter (tailcone on or tailcone off). These issues are being reviewed by the OSF Management Council with JSC and FRC on October 8, 1975.

The role of man-in-the-loop, especially during landing, rollout and braking, needs re-examination as the program reaches the point where avionics capability and limitations are better known.

Response: The Space Shuttle Program engineering simulation activity has been reviewed as a part of the overall avionics development plan. This review reconsidered all the simulation requirements and adjusted the plan to better balance the design freeze dates with the availability of adequate engineering data. The final decisions on the role of man-in-the-loop particularly during landing have not been made and are not scheduled until early 1976. During this time period, ADL testing including some tie with the hydraulic systems will have further defined the control system characteristics. Gain and brake characteristics together with landing aids analysis need more work before final decisions in this area are committed. The program is in agreement with the necessity for good judgment coupled with adequate data in this area. Reviews of the specific landing characteristics and techniques are planned.

Contingency analyses especially for aborts, ditching, landing accidents, and range safety should be completed early enough to assure design solution rather than operational work-arounds.

Response:

ABORTS

(a) The present abort analysis effort is being concentrated on those cases with the highest probability of occurrence. These are the intact abort cases and include the following:

1. Loss of thrust from one SSME.

2. Loss of TVC for one SSME.

3. Loss of thrust from one OMS engine.

4. Loss of TVC for one axis of SRB.

The aborts with a low probability of occurrence are referred to as the contingency abort cases. These cases are being studied, but to a limited degree, in consonance with their low probability of occurrence. Contingency abort cases include the following:

1. Loss of thrust from two or three SSME's.

2. Loss of TVC for two or three SSME's.

3. Loss of TVC for two or more axes of an SRB.

4. Premature Orbiter separation.

5. Failure to separate SRB from Orbiter/ET.

For certain situations, it is not practical to provide for abort solutions. For these cases, appropriate safety margins and high factors of reliability have been included in the Space Shuttle design to preclude their occurrence. These cases include the following:

1. Major structural failure.

2. Complete loss of guidance and/or control

3. Failure to ignite one SRB.

4. SSME or SRB hardover.

5. Failure to separate Orbiter from ET.

6. Premature SRB separation.

Ditching

(b) Orbiter ditching tests have been conducted at Langley Research Center. Based on these tests, the Orbiter should be able to land safely on the water, assuming no major structural breakup. Preliminary structural analysis indicates structural breakup will probably not occur for reasonable ditching conditions. There is a possibility of the side egress door jamming during ditching. Alternate ways are being studied to evacuate the Orbiter in case the egress door is jammed during ditching.

Landing Accidents

(c) Analysis is being conducted by JSC and LRC on the energy absorption capability of the Orbiter during landing accidents. The purpose of the analysis is to determine the ability of the crew compartment aft bulkhead to absorb payload loads resulting from landing accidents.

Range Safety

(d) The Range Safety System PDR is scheduled for October 15 through November 7, 1975. This system, baselined over a year ago, has not yet been approved by the Air Force Eastern Test Range (AFETR). In order to resolve the issues raised concerning range safety requirements, a joint NASA-USAF Ad Hoc Committee is being formed to conduct a technical analysis of the hazards of Space Shuttle flights, both developmental and operational, and to trade off hazards against related launch azimuth constraints and vehicle reliability in order to determine a logical approach to assuring public safety. Alternatives will be recommended to NASA management and the Commander, AFETR, for decision.

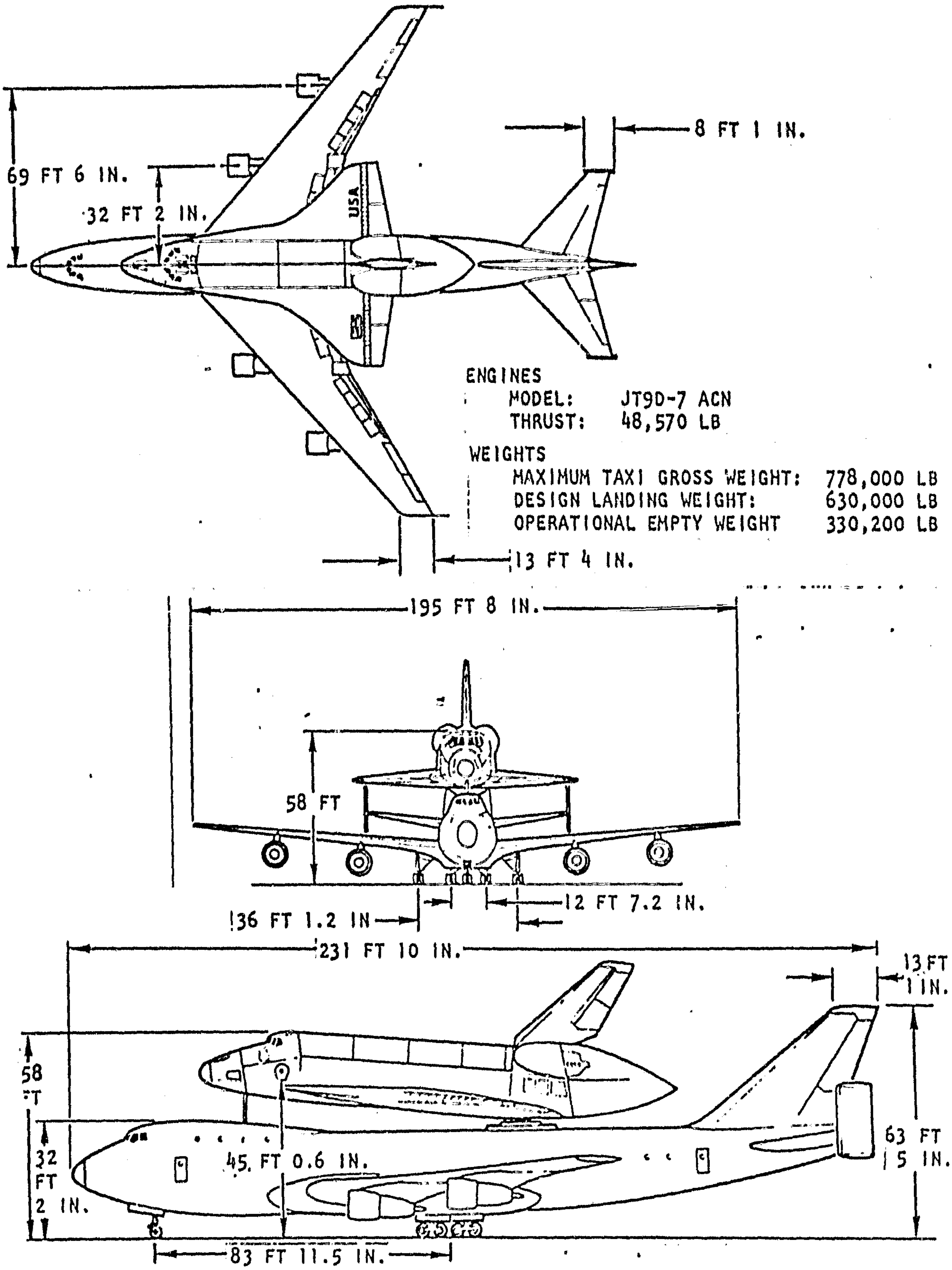

8 FT 1 IN.
69 FT 6 IN.
32 FT 2 IN.
USA
ENGINES
MODEL: JT9D-7 ACN
THRUST: 48,570 LB
WEIGHTS
MAXIMUM TAXI GROSS WEIGHT: 778,000 LB
DESIGN LANDING WEIGHT: 630,000 LB
OPERATIONAL EMPTY WEIGHT 330,200 LB
13 FT 4 IN.
195 FT 8 IN.
58 FT
36 FT 1.2 IN
12 FT 7.2 IN.
231 FT 10 IN.
13 FT 1 IN.
58 FT
32 FT 2 IN.
45 FT 0.6 IN.
63 FT 5 IN.
83 FT 11.5 IN.

FIGURE 8-2

THE ALT ORGANIZATION

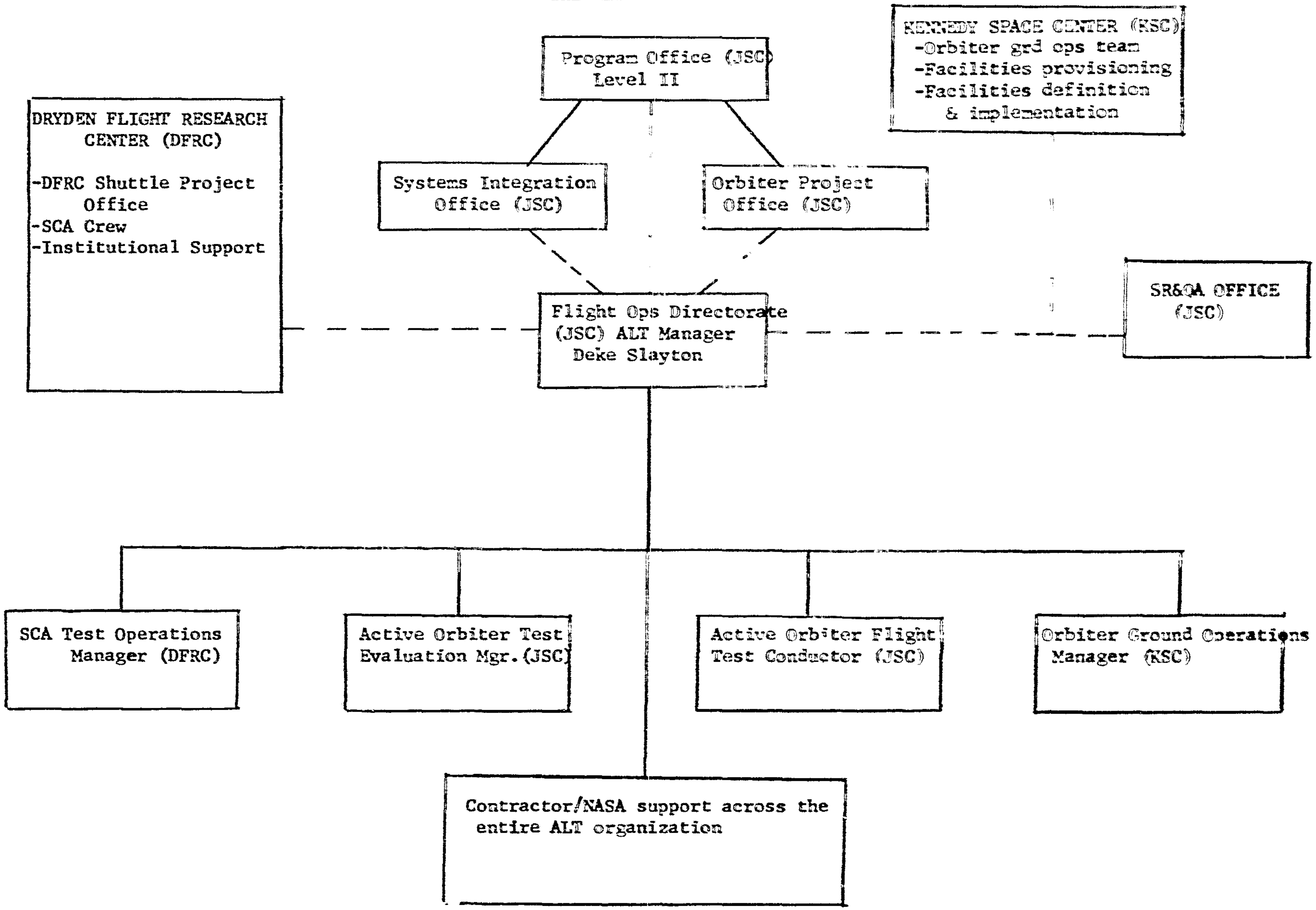


FIGURE 8-3

THE OFT ORGANIZATION

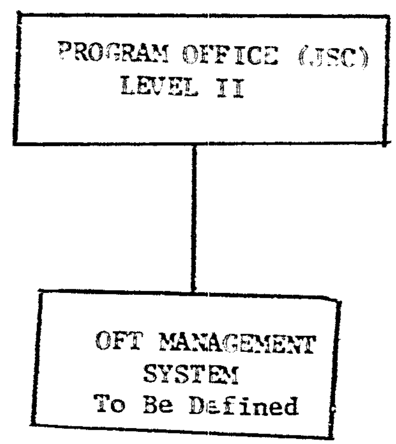


FIGURE 8-4

TYPICAL ALT PROFILE

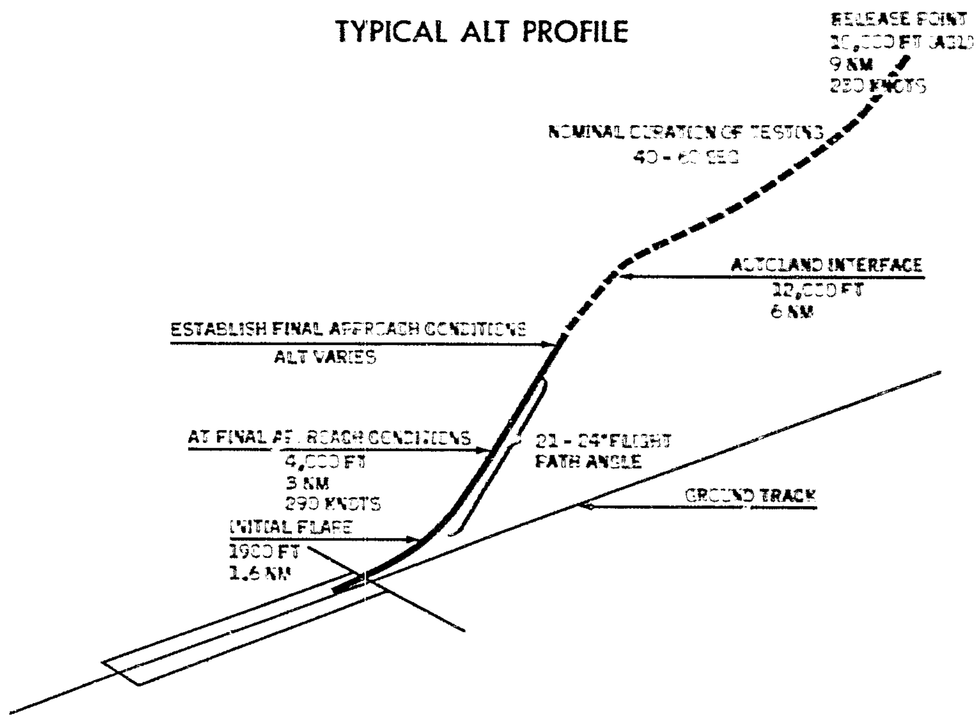


FIGURE 8-5

BASELINE ALT MISSION PROFILE

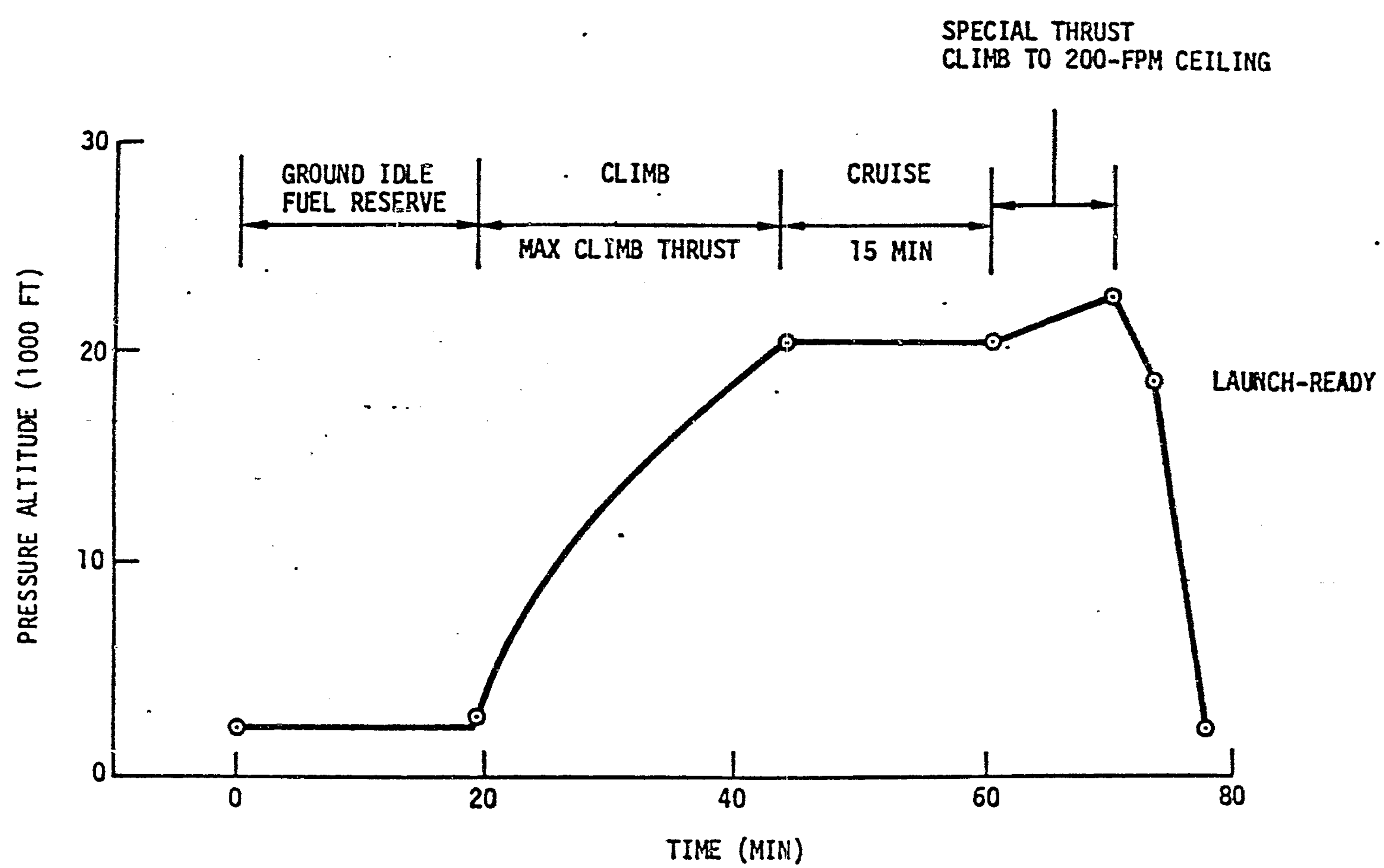


FIGURE 8-6

DEFINITION OF TERMS

- FLOAT TIME: THE Δt, ON THE NOMINAL TRAJECTORY, BETWEEN THE TIME OF TOUCHDOWN AND THE TIME THE VEHICLE FIRST ACHIEVES AN ACCEPTABLE TOUCHDOWN $\dot{h}$ (~10 FPS)

FINAL MANEUVER MARGIN: THE Δg CAPABILITY OF THE VEHICLE AT THE DESIGN TOUCHDOWN POINT

- ENERGY MARGIN: THE FLIGHT TIME POTENTIAL REMAINING AT THE DESIGN TOUCHDOWN CONDITION

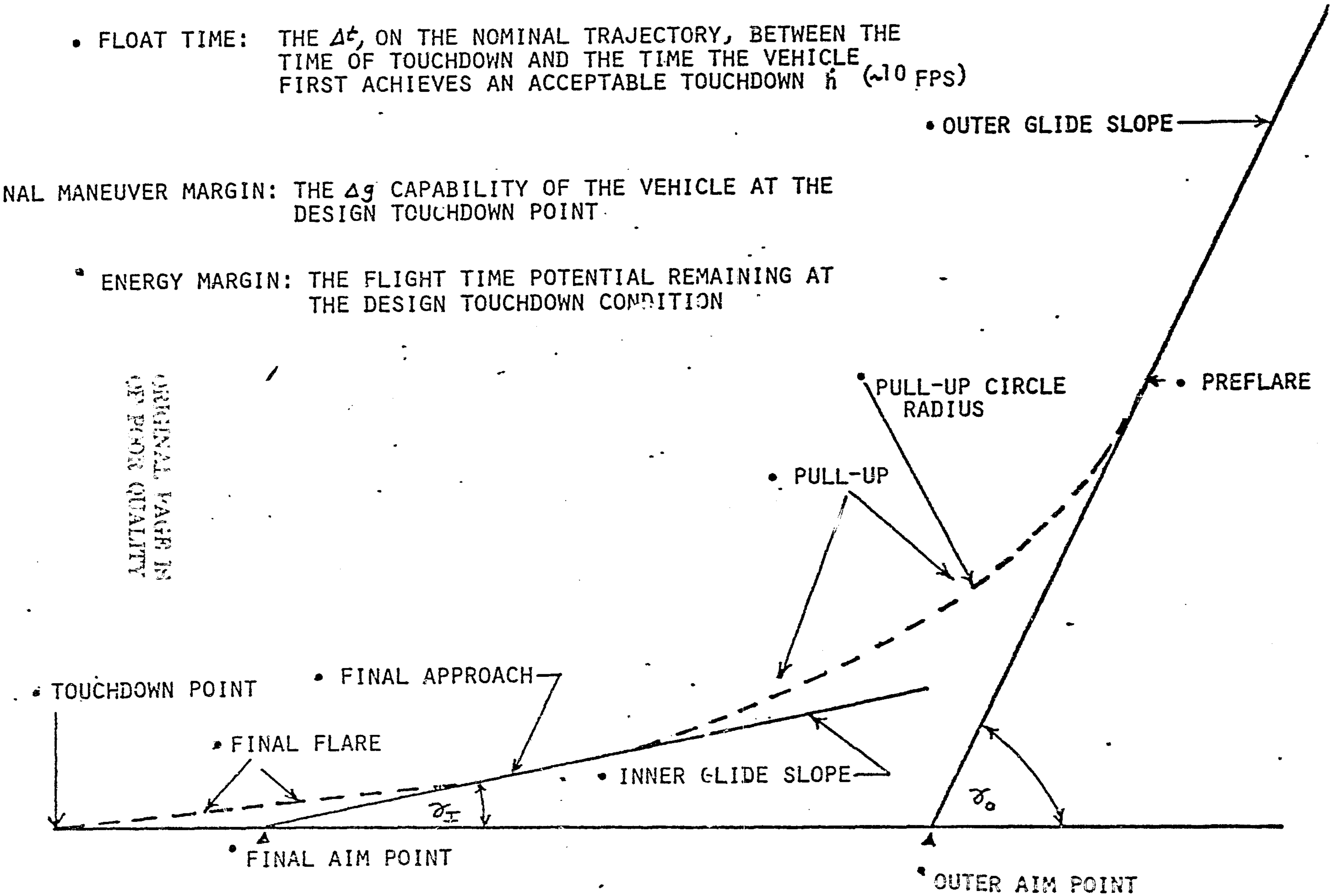


FIGURE 8-7

REQUIREMENTS FOR UNPOWERED LANDING

BASIC PROBLEM

- VEHICLE PERFORMANCE IS DEFINED RELATIVE TO AIR MASS
- GUIDANCE PERFORMANCE IS DEFINED RELATIVE TO R/W
- BOTH PROBLEMS MUST BE CONSIDERED CONCURRENTLY

REQUIREMENTS

- VEHICLE MUST HAVE SUFFICIENT EXCESS ENERGY TO ACHIEVE $\gamma = 0$
- VEHICLE MUST LAND ON, AND STOP ON, R/W

CONTROLLED PARAMETERS

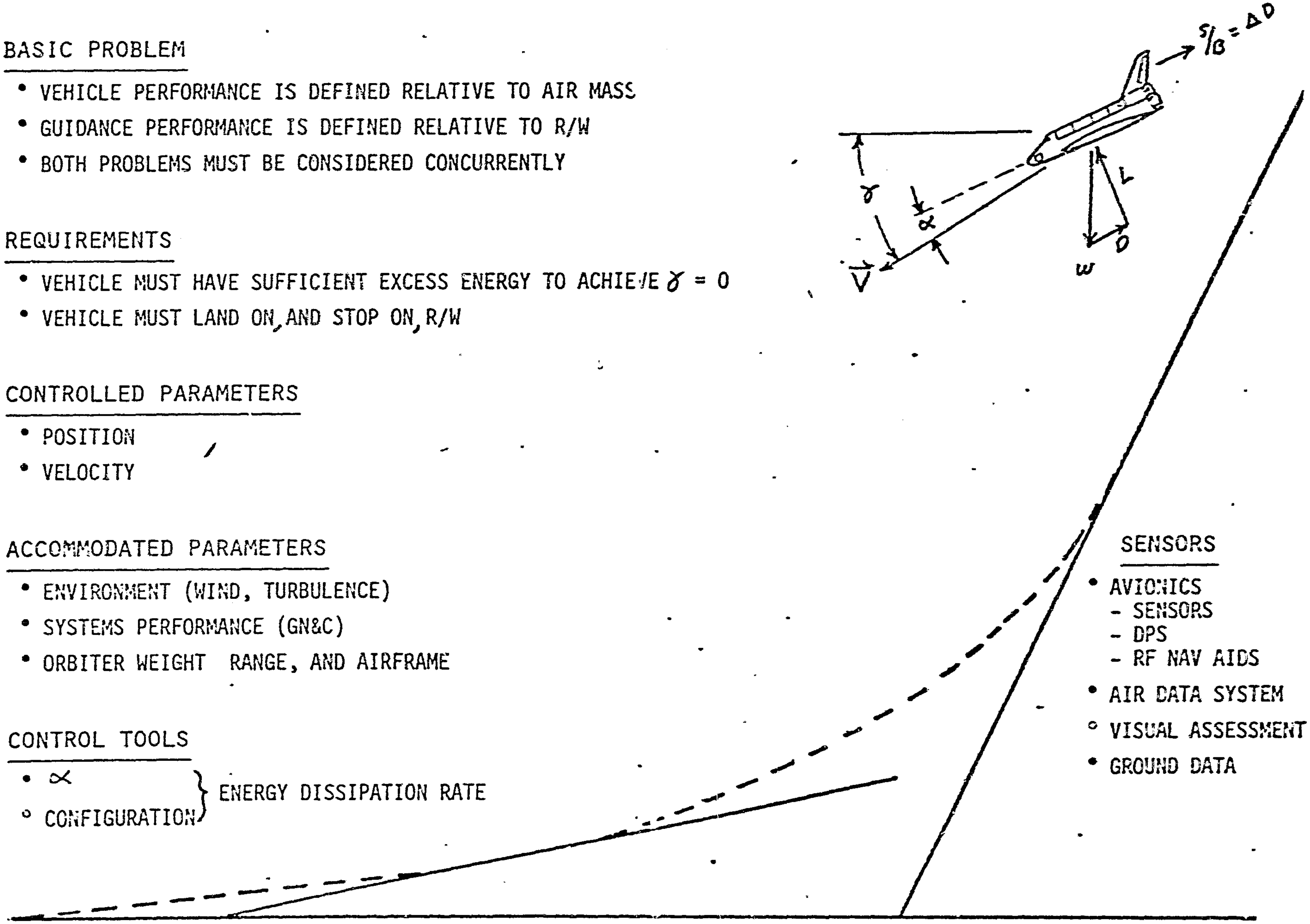
- POSITION
- VELOCITY

ACCOMMODATED PARAMETERS

- ENVIRONMENT (WIND, TURBULENCE)
- SYSTEMS PERFORMANCE (GN&C)
- ORBITER WEIGHT RANGE, AND AIRFRAME

CONTROL TOOLS

- α } ENERGY DISSIPATION RATE
- CONFIGURATION }



SENSORS

- AVIONICS
  - SENSORS
  - DPS
  - RF NAV AIDS
- AIR DATA SYSTEM
- VISUAL ASSESSMENT
- GROUND DATA

FIGURE 8-8

CONSTRAINTS

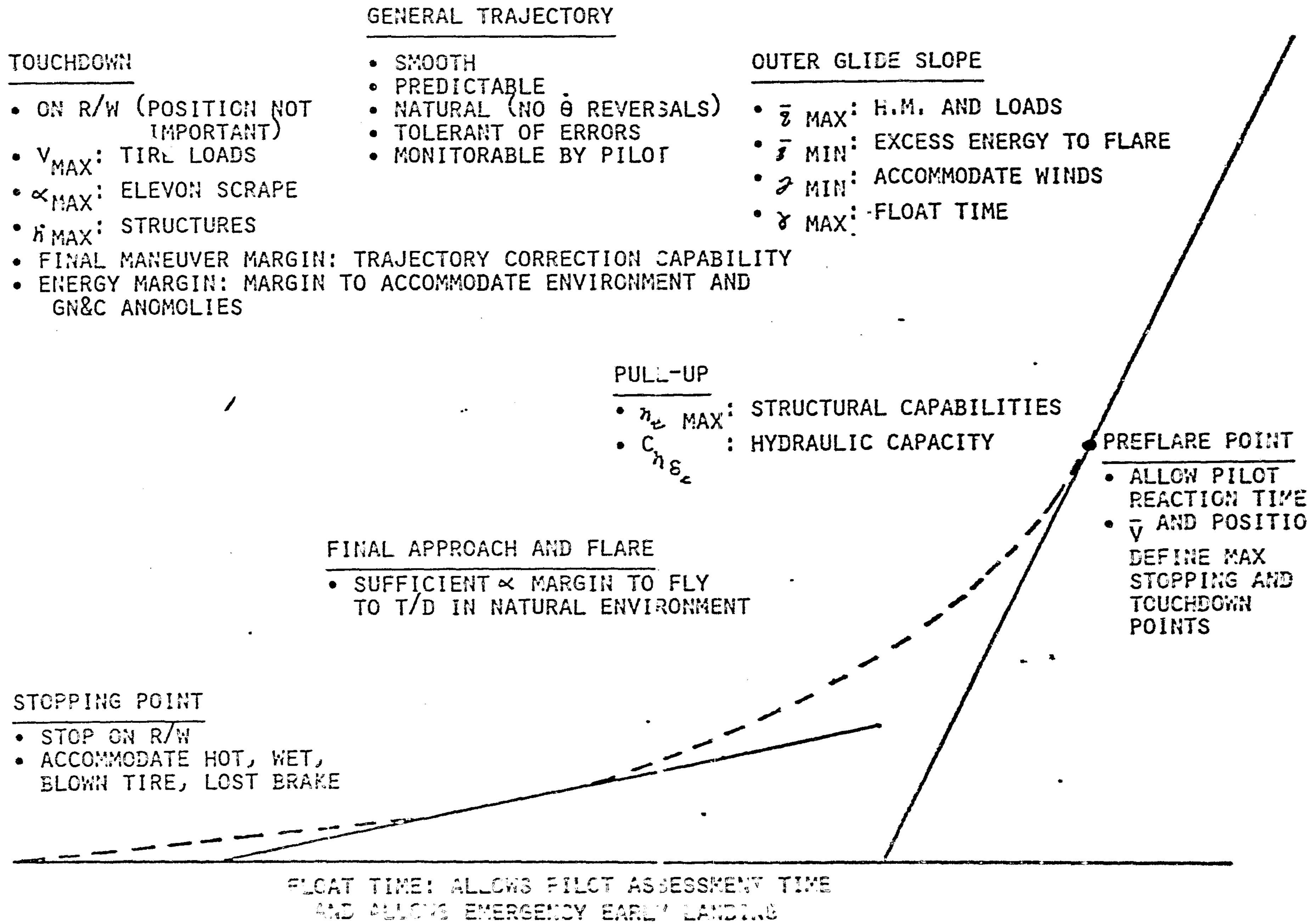


FIGURE 8-9

AUTOLAND APPROACH LOGIC

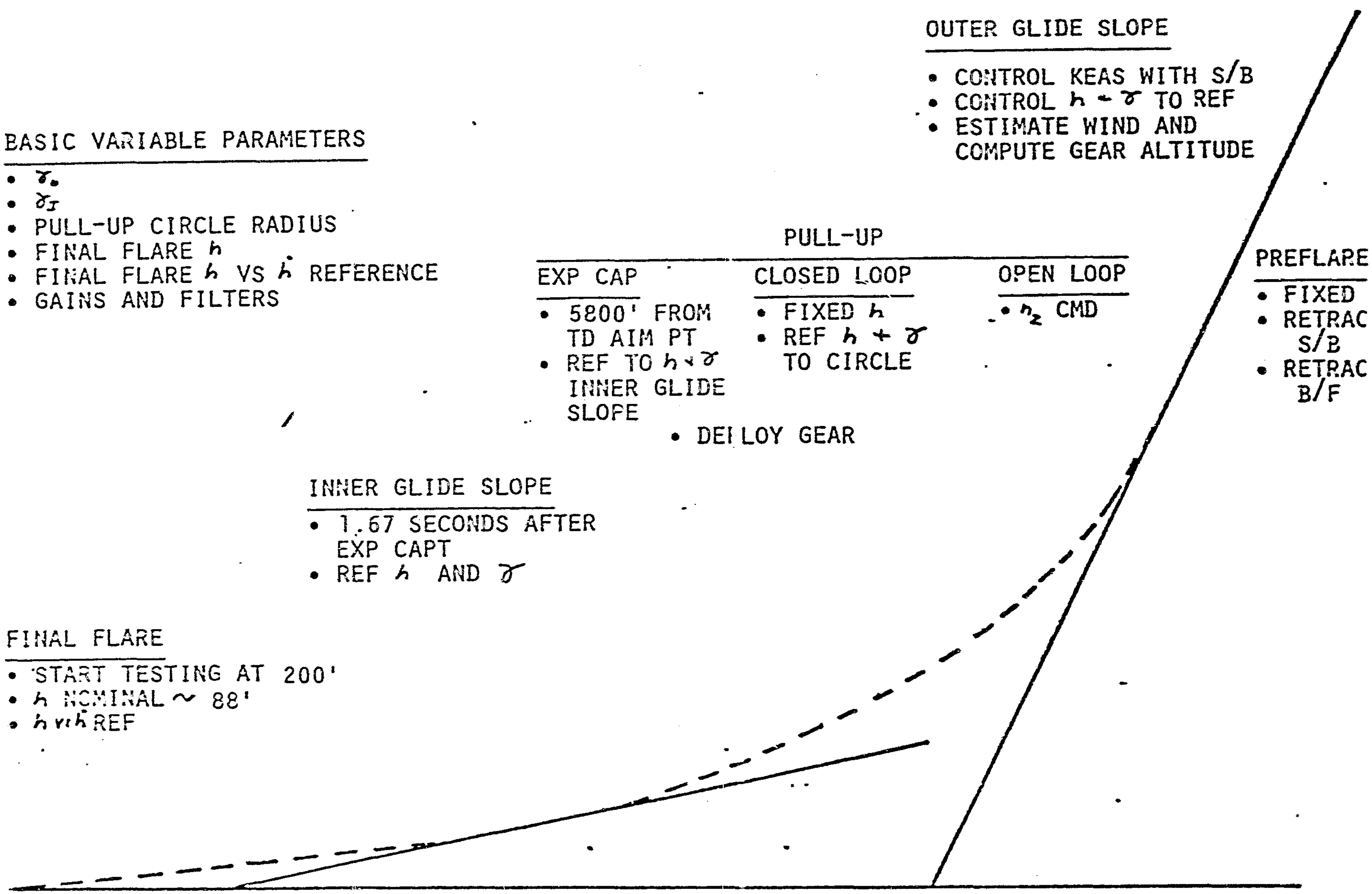
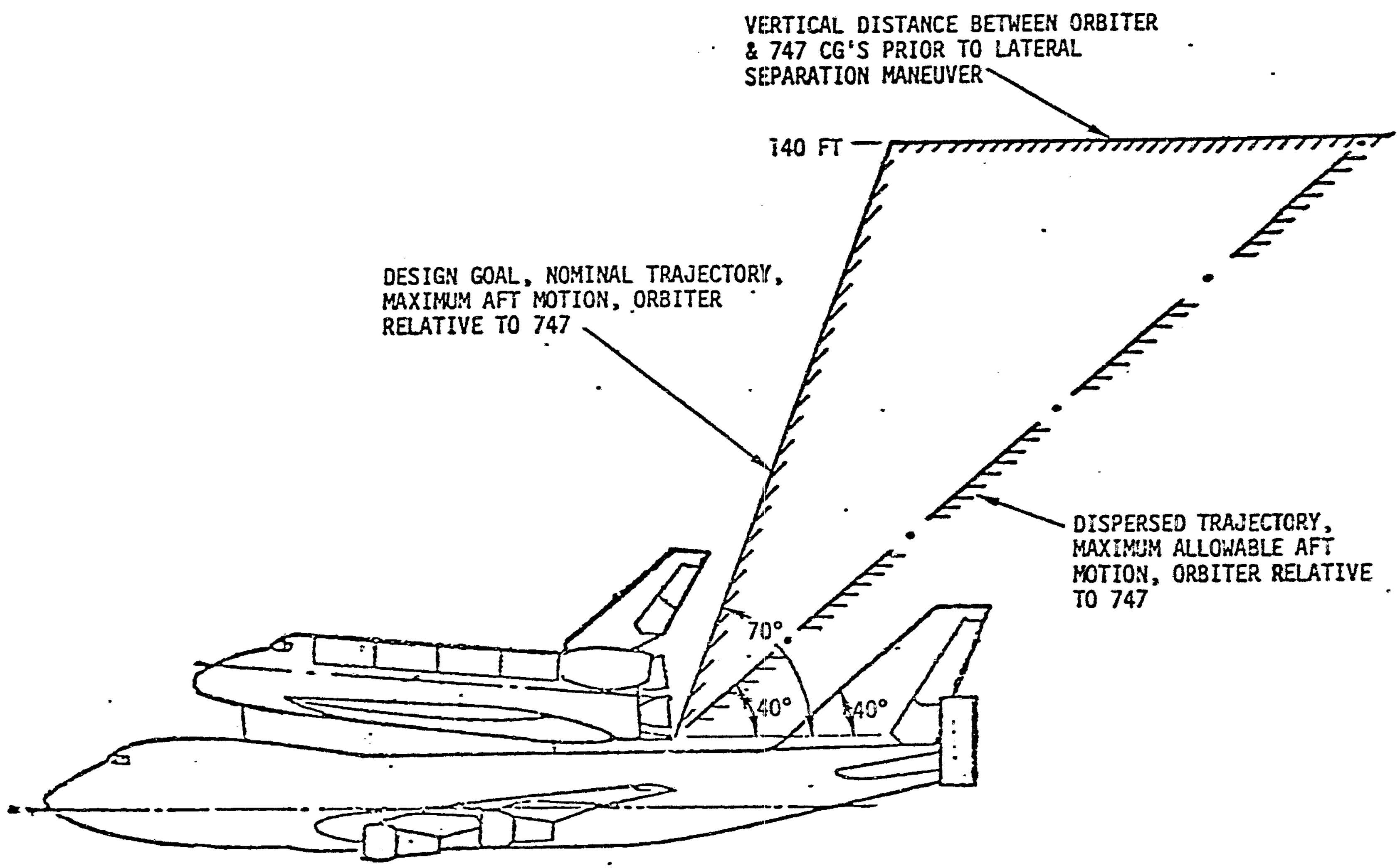
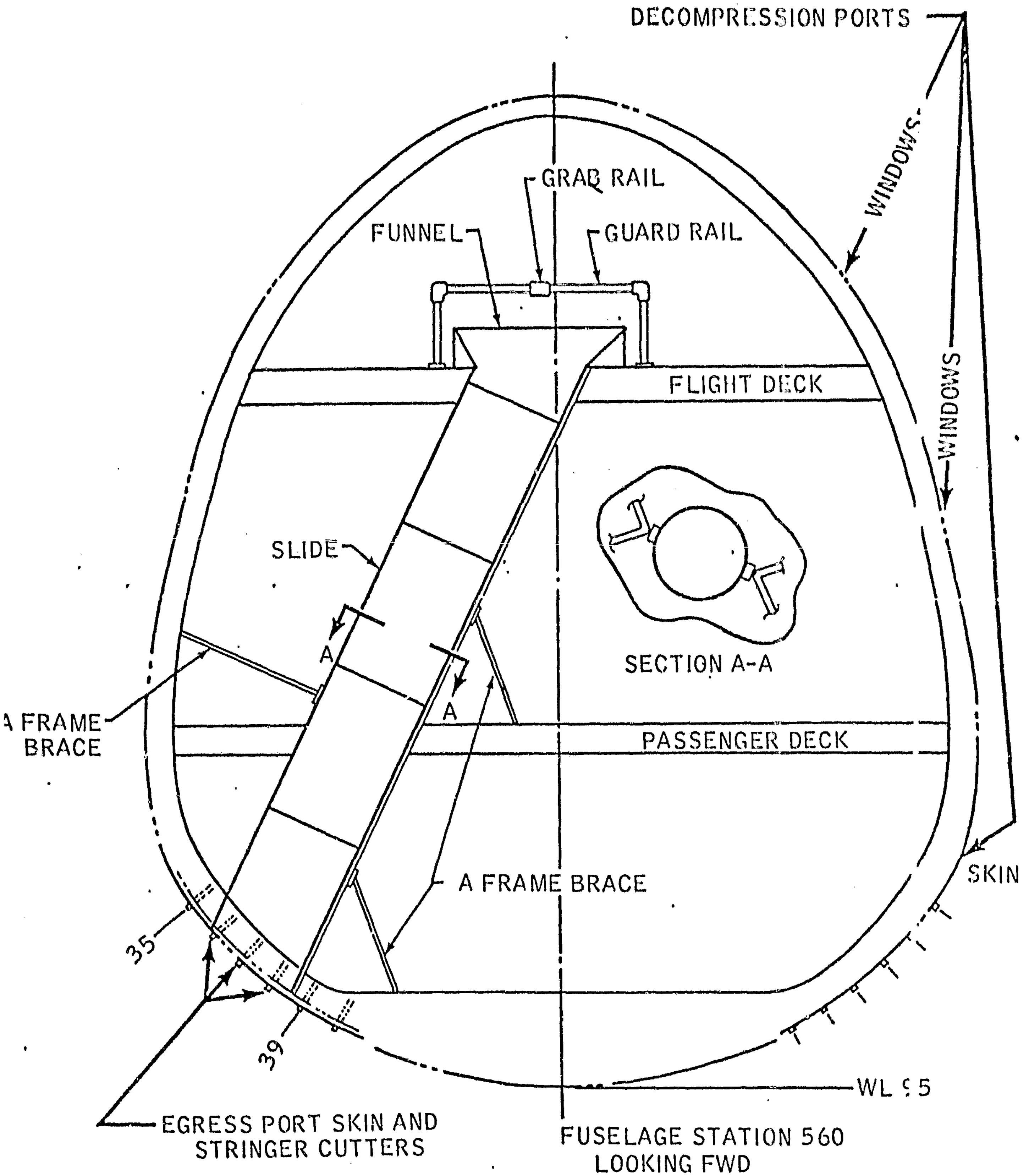


FIGURE 8-10

SEPARATION CLEARANCE REQUIREMENTS





SCALE: APPROX. 1" = 20"

FIGURE 8-12

INNER AND OUTER PANEL SEVERANCE SYSTEMS

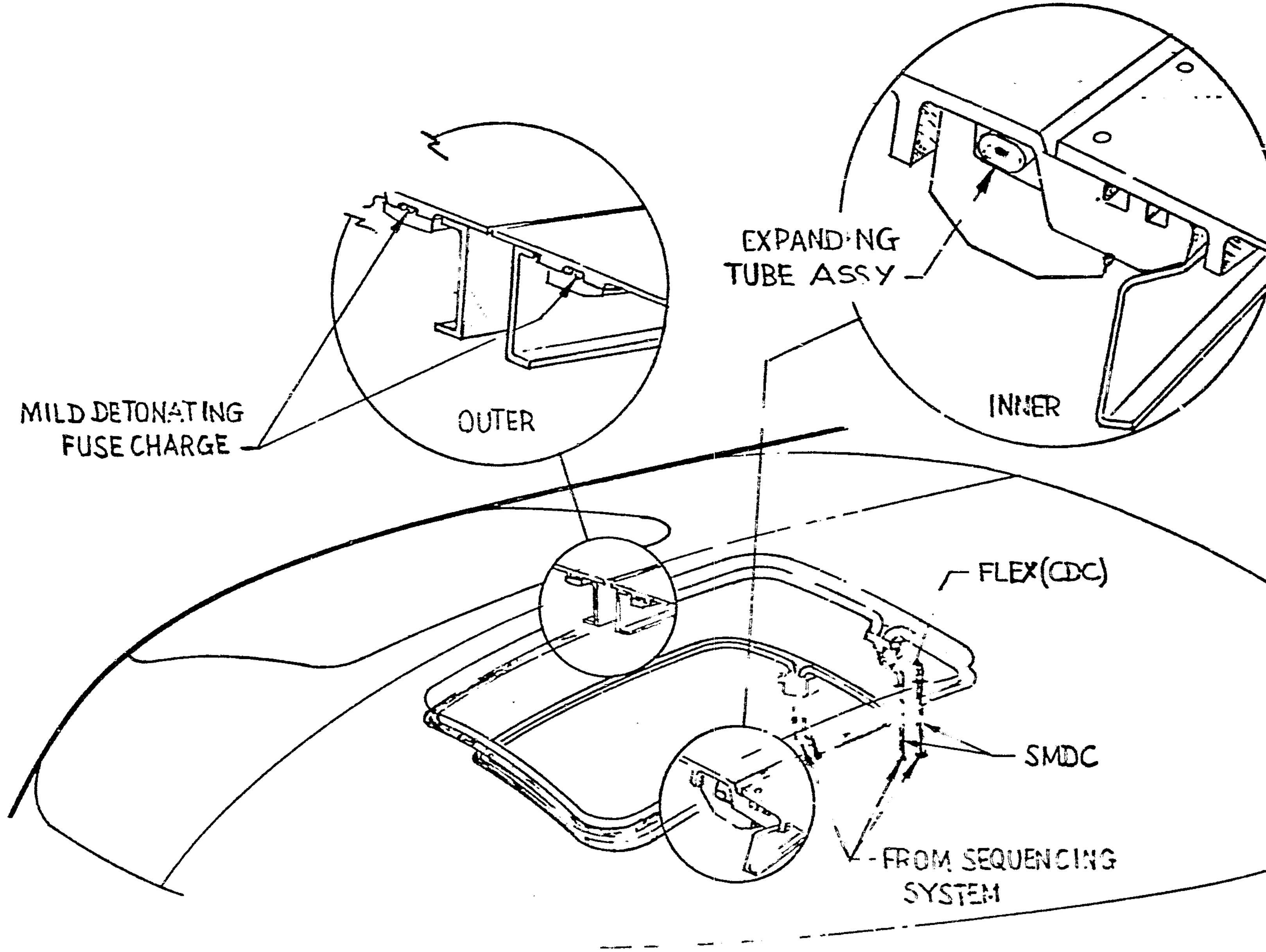


FIGURE 8-13

Permanent (Type I) Structural Modifications

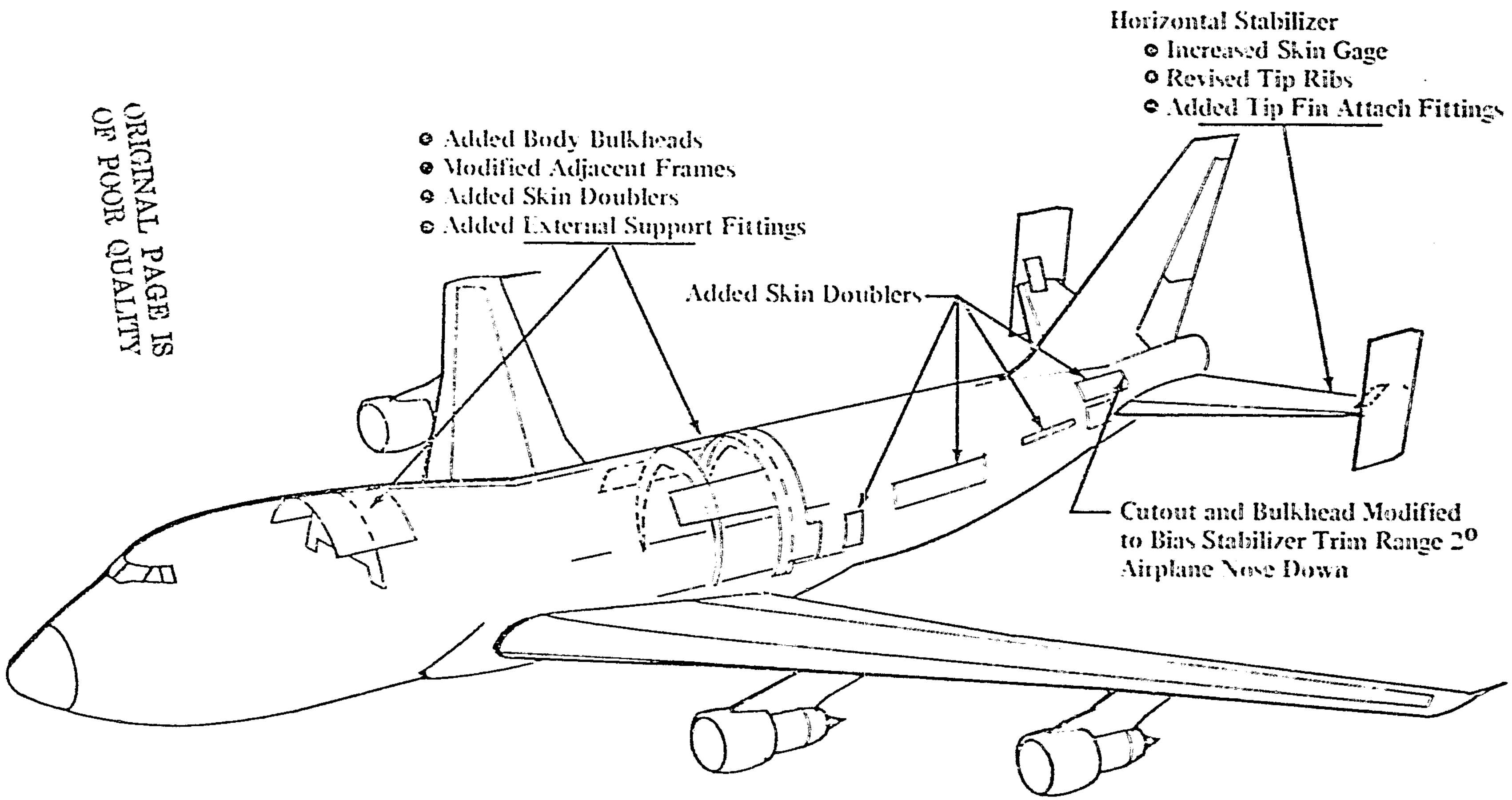
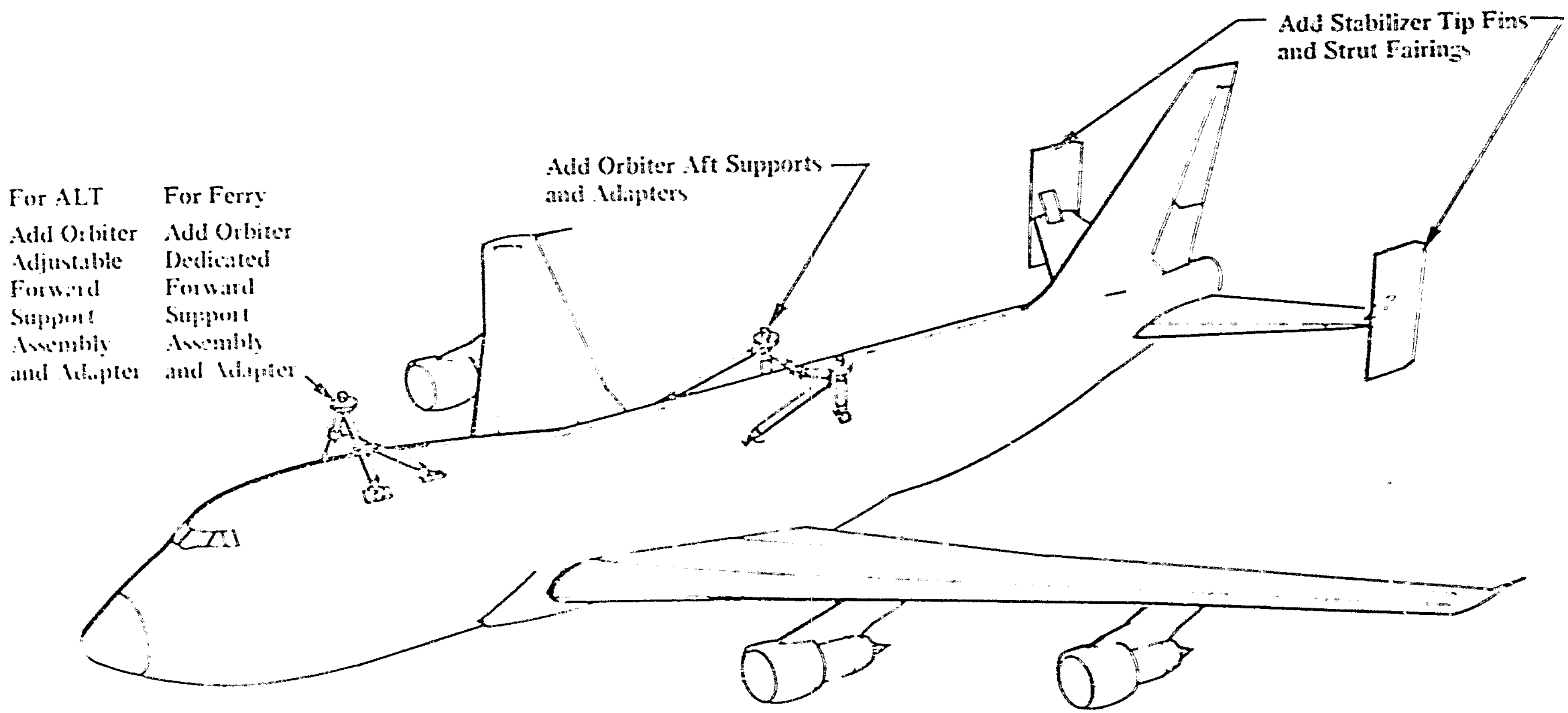


FIGURE 8-14

Removable (Type II) Structural Modifications



9.0 EXTERNAL TANK

9.1 Introduction

Information contained in this section of the report is current through the second quarter of calendar 1976. The latest data includes information for the period through the External Tank Quarterly Review in May 1976, which was conducted at the Michoud Assembly Plant in Mississippi. This overview covers the design status, weight status, development and qualification tests, significant concerns and issues associated with this program. The results of hazard analyses and failure modes and effects analyses are contained in Section 6 (Risk Management) of this report. Discussion of schedules and milestones are provided where it is felt that they have a bearing on the status and/or problem resolution or interfaces with other Shuttle elements.

The External Tank consists of five systems - (1) structures, (2) propulsion, (3) electrical, (4) thermal protection, and (5) interface hardware. Related ground support equipment is discussed in the GSE section of this report.

9.1.1 Background Description on the System

Most active components for the propellant system are contained in the Orbiter to minimize throwaway costs. At liftoff, the External Tank (ET) contains approximately 1,550,000 pounds of usable propellant. The liquid hydrogen tank volume is 53,000 ft^3 and the liquid oxygen tank volume if 19,500 ft^3. These volumes include a 3% ullage

provision. The hydrogen tank is pressurized to a range of 17-19 psig and the oxygen tank to 20-22 psig. Antivortex and slosh baffles are mounted in the oxygen tank to minimize liquid residuals and to damp fluid motion. Five lines, three for the hydrogen and two for the oxygen, come together with the same number of lines in the Orbiter at the ET/Orbiter interface. Both tanks are constructed of aluminum alloy skins with support or stability frames as required, and their skins are butt-fusion-welded to provide reliable sealed joints. Spray-on foam insulation (SOFI) is applied to the complete outer surface including the sidewalls and the bulkheads. SLA-561 ablator material is applied to selected areas, such as the attachment structures, where shock impingement causes increased heating.

9.1.2 Structures

Structural design is complicated by the need to meet the interactive load effects resulting from (1) the temperatures and pressure requirements of the internal propellants, (2) external heating and pressures due to aerodynamics, and (3) the loads associated with Orbiter and Solid Rocket Booster interactions during the ascent phase of the mission. The hydrogen tank is a fusion-welded assembly of barrel sections, I-Ring frames, and dome sections. A frame at the juncture of the forward dome and forward barrel contains an integral flange which joins the hydrogen tank to the intertank and also provides

the structure for the Orbiter forward attach point. The oxygen tank is of ogive shape to reduce aerodynamic drag and aerothermodynamic heating. A ring frame at the juncture of the dome and cylindrical section contains an integral flange for joining the oxygen tank to the intertank. The intertank is a skin/stringer/frame structure of cylindrical shape and includes a heavy beam which spans the intertank. The ends of the beam contain the SRB thrust fittings which are the ET/SRB forward interface points. Flanges at either end of the intertank provide the attachment to both the oxygen and hydrogen tank elements. A frame at the juncture of the aft dome and the aft barrel of the hydrogen tank contains the structure for the aft SRB attachment and also the structure for the aft Orbiter attachment.

9.1.3 Propulsion System

The ET contains all the hydrogen and oxygen for the Orbiter's main engines. Also, the ET propulsion system serves the primary function of delivering the oxidizer and fuel to and from the propellant tanks and the Orbiter interface. Delivery rates to the Orbiter are approximately 45,300 gpm for liquid hydrogen and 17,000 gpm for liquid oxygen. All controls and valves are located in the Orbiter except for the LOX and LH_2 vent/relief valves, the tumbling-system pyro valve, check valves in the helium inject line, and those valves integral to the interface disconnects. Propellants are loaded

and off-loaded through the Orbiter into the ET. As for loading rates, maximum flows are 12,000 gpm for hydrogen and 5,000 gpm for oxygen.

9.1.4 Electrical System

The electrical system provides for propellant level sensing, instrumentation functions, electrical power distribution, tumbling capability and light ning protection. There are two distinct sets of instruments, the operational instrumentation and the development flight instrumentation. The development flight instrumentation is carried on the first six flight articles. Subsequent flights will have only operational instrumentation, which is hard-wire interconnections of sensors without ET electronics. All ET electrical power is derived from the Orbiter.

9.1.5 Thermal Protection System

The TPS performs a multipurpose role during prelaunch and flight phases. Its major functions are (1) to maintain the primary structure and subsystem components within design temperature limits, (2) control prelaunch boil-off rates, (3) contribute to maintenance of proper propellant temperature at Orbiter interfact, (4) prevent liquefaction of air on the hydrogen tank surface, and (5) help prevent accumulation of ice on the external surfaces of the ET.

During the ascent phase the TPS helps to minimize the unusable

liquid hydrogen resulting from thermal stratification. During entry of the ET, structural temperatures and tank pressure contribute to the tank fragmentation process and the resultant debris size and impact footprint. The TPS assures safe separation from the Orbiter and low altitude fragmentation to meet a required 100 x 600 n.mi. footprint.

The types, areas of location and thicknesses were designed to handle worst case environments induced by an "abort-once-around: condition. Briefly the TPS materials and their application are as follows:

> SLA-561 is used in two forms, molded (SLA-561m) and sprayed (SLA-561s).
>
> CPR-421 is a fluorocarbon-blown, rigid-foam (polyisocyanurate).

with strength characteristics, and dimensional and thermal stability at low or high temperatures, that exceed those of standard urethane foam. A more complete description of the TPS usage is shown in Table 9-1.

9.1.6 Interface Hardware

The External Tank interfaces with the two Solid Rocket Boosters, the Orbiter, and with the launch facility. SRB interfaces are six flight-separable structural attach points and electrical connections to allow Orbiter-to-SRB communication and control. Orbiter inter-

faces include three flight separable structural attachments as well as electrical, propellant and pressurization umbilicals. A launch facility umbilical interface located at the intertank provides ground services to purge the intertank and to actuate vent valves for prelaunch operations. A more detailed description of the interfaces can be found in Figure 9-1.

9.1.7 Range Safety

Because of incompatibilities between the Shuttle baseline range safety system and the Air Force Eastern Test Range safety requirements a decision has been made to implement a new baseline Flight Termination System, which includes an External Tank propellant dispersal system. It will be carried on operational flights as long as required. The system will be "triplex" in that charges will be placed in the External Tank and one in each of the SRB's. The details of the exact system design are still under consideration. Trade studies are now underway regarding: ET electronics redundancy versus cross-strapping; intertank ordnance versus linear tank length charges; SRB charge; and redundant open-loop versus closed-loop dual initiator.

9.1.8 Schedules

A brief look at the Level I (NASA Headquarters) controlled milestones for the ET identifies the program's accomplishments and the

work ahead.

- Completed Preliminary Design Review (PDR)	Sept. 1974
- Completed Critical Design Review (CDR)	Nov. 1975
- Complete delivery of Main Propulsion Test Tank to NSTL	May 1977
- Complete delivery of ET Ground Vibration Test Article to MSFC	March 1978
- Deliver first flight tank to KSC for FMOFT	Sept. 1978

9.2 Observations

A general overview of the ET program indicates that the program's management systems have been in place and working well for some time now. The basic detail engineering design/drawings are about 75% complete with full assembly and installation release due sometime in the third quarter of 1976. A study has been in progress for some time to determine if the Structural Test Article test requirements can be simplified and reduced. This, of course, is a cost/schedule saving procedure which involves an analysis of what each test returns for the money and time invested. Many of the actions (RID's) from the CDR are still being worked, while all those from prior milestone reviews have been closed. Manufacturing facilities (plant, tooling, etc.) and procurements of materials and effort appear to be supporting the ET program at this time. Specific areas of concern and efforts to resolve them are discussed in the following segments of

this section of the report.

9.2.1 Review System

With the completion of the External Tank Critical Design Review in November 1975, the ET program is considered sufficiently mature to allow fabrication of the deliverable tanks for flight. The review established a baseline configuration. Almost all changes will need to be approved by MSFC. In addition to the day-to-day activities normally conducted at both MSFC and at Martin Marietta, regular reviews and Shuttle Panels dealing with the External Tank continue to be the major technical management control exerted on the program. Reviews include the ET Quarterly Technical Management Review conducted at MSFC or the Michoud Assembly Facility (MAF), weekly teleconference meetings to examine problems and expectations, and the Configuration Control Board operations. Further discussion of what transpired at the CDR will be helpful in understanding the depth of the reviews conducted on the ET.

The CDR was conducted at the NASA Michoud Assembly Facility, in New Orleans, Louisiana, between November 10 and 21, 1975. There were a total of 363 Review Item Discrepancies (RID's) submitted. These were distributed as follows:

Structures	129
Propulsion	77

Total = 363

Electrical	98
TPS	59

Of these RID's 81 were withdrawn, combined with others or disapproved, leaving 282 "working" items. More than half of these have been closed out since the CDR by completion of the work or that the activity is fully in process. The remainder are being worked with expected completion before mid-year 1976.

The CRD may then be summarized as follows:

(a) Structures and propulsion system design has been thoroughly reviewed and found to be technically adequate. Production can proceed with baseline design.

(b) The TPS baseline concept has been found to be technically sound. Development can continue on that baseline.

(c) The electrical system components review has highlighted three hardware problems - (1) Cryogenic Connectors (Low Temperature Limitations), (2) Ullage Transducers (High Temperature Limitations), and (3) Instrumentation Sample Rates (MUX Impact).

(d) MPTA (Main Propulsion Test Article) requirements require further iteration to match the requirement to vehicle capability.

The action items resulting from the CDR included such things as:

(a) The contractor (MMC) is to perform a cost trade study

on the use of Inconel 718 for the aft SRB thrust fitting. They are to consider the procurement schedule to determine if it would be less costly to change out the material than to continue with the development cost of a titanium fitting.

(b) JSC is to assure that adequate handling and logistic plans exist in support of the MGVT.

(c) Rockwell International, Space Division, is to investigate the problem of overheating of the ullage pressure sensors. MMC is to evaluate other components for compatibility with the predicted gaseous oxygen temperatures. This will apply to both the flight vehicle and the MPTA.

(d) MSFC will review Volume X of the Level II requirements documents and SN-C-005 (contractual specification) and initiate the appropriate change request to make the External Tank contamination requirements compatible with the system contamination control requirements.

There are a number of major Level II working Panels that deal with the External Tank as it relates to (1) the integrated propulsion system (SSPM Directive #24), (2) Range Safety (SSPM #42), and (3) thermal design (SSPM Directive #46) and so on. Since these Panels meet and discuss technical and management problems on a continuous basis, they support the day-to-day operations as well as the major

reviews such as the CDR.

9.2.2 Design Progress

This section will focus on two areas of interest - (1) those design areas that are significant to the operation of the Space Shuttle System as a whole but which have received a minimum of atten tion from the Panel before, and (2) significant concerns regarding design requirements, design implementation, redesign due to test. The test program and its status is covered in another section of this chapter.

9.2.2.1 ET Venting and Tumbling

A liquid oxygen venting system is incorporated into the ET. Along with its associated tumbling system, it is designed to enhance the separation safety between the Orbiter and the ET. The vent system relieves the liquid oxygen tank pressure if it increases to 23-25 psig. The nearly nonpropulsive design limits thrust to less than 50 pounds. The liquid hydrogen tank may vent after separation if the tank reaches a pressure of 20-22 psig, but its direction of thrust will not affect the tumbling motion. The tumbling system associated with the liquid oxygen venting system operates by opening a pyro-operated valve in the nose cap. This allows the oxygen gas to escape through a single port located such that its thrust moves the nose of the External Tank

away from the Orbiter at a slightly greater rate than the rear tank movement to create an increasing rate of tumbling. This energy is not related to the function of separation. The tumbling motion contributes to a more predictable trajectory by preventing atmospheric skip, and helps cause the External Tank to break up into fragments at about 185,000 feet altitude. This technique of entry results in a smaller, more predictable ocean impact area of about 100 x 600 n. mi. for tank pieces.

9.2.2.2 Flight Test Configuration

The first six External Tanks to be used in the Space Shuttle Orbital Flight Test Program (OFT) have additional development flight instrumentation (DFI) over and above that to be used on the operational vehicles. These are installed to confirm the External Tank design, provide for diagnostic analysis to analyze flight anomalies and support operational planning. The instrumentation has been added with a minimum of changes being made to the base vehicle. The changes involved segments of the structure, the propulsion, electronic conditioning and thermal protection systems. An additional Orbiter/ET interface has, however, been added. The DFI electrical system, supplied by Orbiter power, consists of 342 measurements including bus-voltage monitoring and PCM multiplexer BITE monitoring as well as hardware for signal conditioning to assure a compatible data interface with

the Orbiter. The DFI measurements interface with the Orbiter Frequency Division Multiplexer. Measurements associated with POGO, acoustic and other vibration measurements interface with the Orbiter through the ET frequency modulation multiplexer to tape recorders.

9.2.2.3 SRB Thrust Panel

The intertank cylindrical structure consists of two machined thrust panels and six stringer stiffened panels joined mechanically. No weldments are used. The two thrust panels distribute the concentrated axial SRB thrust loads to the LOX and liquid hydrogen tanks and to adjacent intertank skin panels. The panels are selectively machined with tapered skin thicknesses, and 26 external parallel ribs are integral with each panel. The panels are machined from aluminum plate, 2219-T87, to a finished size of 2.06" x 130" x 271" height. This panel must then be formed into the 165" radius after machining. It contains thicknesses ranging from 2" around the SRB Beam to 0.135" in the web sections. AVCO, the subcontractor, planned to hot-form these panel at about 375^{o} in their "Bump Press." Because these panels are already in the so-called "T87" condition no temperature higher than 325^{o} is actually allowed. Given their experience on another contract, AVCO indicates that if the hot-forming is to take place at 325^{o} F. the panel will break. The options under consideration are: (a) ship the job to Denver Martin Marietta where there is a "Break Press" of suffi-

cient size, or (b) consider changing the material to the T37 condition for the fabrication process and then age it to the T87 condition. A decision has not been made and the Panel will follow this item.

9.2.2.4 Range Safety Implementation for the ET

The following tentative agreements have been reached regarding that portion of the range safety flight termination system that is to be designed for the External Tank:

(a) The range safety system will be triplex (one per SRB, one on ET).

(b) ET electronics for this system are to be on the ET.

(c) It is assumed that the External Tank termination system may not be required on all launches, and will be designed for easy installation and removal at the launch site.

(d) MSFC is determining the desirability of locating the ordnance in the intertank area versus running a charge the length of the ET.

(e) Studies are being made on the best way to achieve system redundancy. Redundancy is not required if the system is "cross-strapped" from the SRB system. So far these studies indicate there is inadequate antenna coverage during the early part of the ascent flight to support redundancy requirements.

(f) Requirements in Volume X of the Level II Shuttle documents will be changed to meet the "triplex" requirement.

These actions and their implementation will be followed by continuing Panel attention.

9.2.2.5 Structural Loads Updating

In November 1975 the Orbiter/Integration Contractor generated new structural loads indicating that there will be significantly higher liquid hydrogen tank body loads as a result of time phasing of the moment and lateral load combinations. In addition when newer High-Q cases are examined it would appear that High-Q loads will increase the interface loads. As a result it would appear that either a higher pre-pressure or structural beef-up may be required. This area is under study at this time and will also be followed by the Panel in future examinations of the ET.

9.2.2.6 Pulse Code Modulation (PCM) Multiplexer (MUX) Capability

Current data requirements are close to the limits of the hardware to accommodate the data bits. The PCM Mux capability is 16,000 BITS with current usage at about 15,500 BITS. The potential for overload is obvious. Such a problem is not uncommon at this stage of the program. Scrub-down of the requirements for measurements and sampling rates is currently underway. This area will be examined

at future reviews by the Panel.

9.2.2.7 Weight Status

The ET current inert weight is calculated or estimated to be 73,756 pounds. The specification weight at this time is 73,999 pounds. The margin is obviously small and will continue to require stringent management attention. The weight status is based principally on calculations and less than 15% is estimated.

9.2.2.8 Thermal Protection (TPS)

A number of significant issues have surfaced and are in various stages of resolution at this time. Some of these are of particular interest to various Panel members and therefore are discussed here.

(a) Rockwell indicates that revised ascent heating loads are somewhat higher than used by the ET designers in their design of the TPS. RI is currently evaluating their latest calculations of ascent conditions. These calculations, along with further high energy plasma arc/wind tunnel testing, should provide a more accurate picture of the thermal and structural load provisions to be made for the ET. The greatest effect appears to be on the forward section of the liquid oxygen tank and on the intertank. There is less impact on the liquid hydrogen tank. If the loads are higher there will be substantial increase in the amount of insulation required and a

corresponding growth in weight. Both the trajectory parameters and the analysis methodology using lower altitude trajectory, wind tunnel data recovery factors, and roughness effects are under review.

(b) There is possibility of the lift-off of the CPR-421 insulation at the interface between the CPR insulation and the so-called "super light ablator" material. This would be due to the heat of reaction from CPR in liquid phase expanding the volume of air in the ablator material. The pressure increase forms voids at the interface of the two materials which then bubble out. There is also a possibility that the CPR-421 interacts with the adhesive and primer used to hold the insulations to the tank. Finally, the angle at which the two materials interface may result in aerodynamic lift-off. All of these areas are being studied and appropriate tests are underway.

(c) Material development and installation methods are still causing some problems. The low strength of thick SLA-561s at the substrate is under intensive study and test to resolve this material problem.

(d) Minimization of damage to the Orbiter TPS tiles from ice on ET protuberances is receiving intensive study. There are more than 70 that can collect ice. Studies focus on reducing ice formation to a minimum by further protection of the ET areas of concern and

understanding the tolerance of the Orbiter tiles to damage from ice impact including the extent of tile thermal degradation.

9.2.2.9 Lightning Protection

The ET design incorporates features to protect the structure and subsystems from the direct and indirect effects of triggered atmospheric electrical discharges during flight operations. The ET is designed to function after an initial strike of 200,000 amperes peak at the ET lightning rod and a second lightning strike of 50,000 ampere peak across the ET body while it is in motion. Lightning protection criteria for the Space Shuttle Program are found in detail in the document JSC-07636 with changes 1 and 2 updating it to March 1976. Lightning protection is provided by the launch site until liftoff. Thereafter, the bare 20 inch long, 20 degree nose cone at the tip of the ET nose cap serves as a lightning rod. Preliminary lightning tests indicate that a 0.03 inch wall-gauge gaseous oxygen line running along the outside of the tank can accommodate restrike currents with a forward motion as low as one foot per second. Further lightning tests are being conducted to confirm the design. Simulated lightning tests indicate the minimum (0.08 inches) the skin gauge on the liquid oxygen tank will withstand expected strike currents.

9.2.3 Major Ground Tests

There are three major ET ground test programs, or better still, three programs using the ET as a major test item: (1) Structural Tests, (2) Main Propulsion Test, and (3) Ground Vibration Test.

Structural tests will be performed at the MSFC facilities to confirm structural analyses and to verify the design. The general objectives of this program are:

(a) Verify structural integrity of the ET for critical internal and external design limits, yield and ultimate loads.

(b) Obtain data to substantiate dynamic and stress analyses.

(c) Verify the structural integrity of the interface hardware.

(d) Obtain influence coefficients (stress and deflection) for structural and functional characteristics.

(e) Verify the structural integrity of the substructure and of primary structure bracketry.

(f) Determine growth capability for future missions.

(g) Determine weight savings candidates for the production article.

The hardware used for these tests has been designated the STA or Structural Test Article. It consists of the following major test assemblies: Intertank Static, LOX Modal, LOX Static, Liquid Hydrogen Static. One LOX tank and one LH_2 tank simulator section

are used in conjunction with the STA elements.

The Main Propulsion Test (MPT) program is to be performed at the National Space Technology Laboratory (NSTL) in Mississippi. It will assess and verify the integrated Space Shuttle main propulsion system performance. The MPT External Tank will be mated to a simulated Orbiter midbody made of boiler-plate, and a flight weight aft fuselage with the main engine cluster. The ET MPT article is flight configured with modifications to meet the needs of the test. A total of fifteen test firings are planned with eleven being either full duration or approaching full duration.

The ground vibration test (GVT) program at the Advanced Dynamic Test Stand at MSFC will measure frequency, mode shapes, and damping characteristics of the mated Space Shuttle vehicle. The GVT External Tank is a flight configured structural article that will be returned to MAF at the completion of the GVT for refurbishment and recycling into a production ET. The experimental results will provide a basis for updating the math model so that follow-on analytical studies will yield refined and more accurate data. Substantiated or updated coupled dynamic math models will provide more confidence in the Orbiter guidance and control system design, POGO analyses, structural load predictions, and flutter analyses in support of the first Space Shuttle flights. It is understood that a 1/4-scale test program is also in the plans.

9.3 Hazard Analyses and Safety Concerns

Both NASA and its contractors have developed a hazard analyses and safety program on the External Tank program that is working well. Typical products are the "Space Shuttle External Tank Critical Design Review Hazards Analysis Report" (MMC-ET-RA01-A dated October 17, 1975) and the "Space Shuttle Safety Concerns Summary Report" (JSC 90090) which includes the ET as a part of the total picture. The elements of the process used by Martin Marietta in arriving at risk assessments include:

(a) Process of hazard identification, analysis and corrective action.

(b) Review and evaluation of changes for hazards.

(c) Trade studies.

(d) Safety assessment summary

(e) Catalogue of hazard and then resolution.

The ET Critical Design Review summarized the hazards at that time and most of them are now resolved.

SYSTEM	HAZARDS	
Structures and TPS	19	
Propulsion and Mechanical	27	
Electrical	10	
Transportation and Support Equipment	2	
TOTAL	58	(Most of these have been resolved)

To provide the reader an understanding of these hazards, the following were selected from the Summary Safety Concerns report:

(a) The impact of ice forming and breaking away from the ET and impacting the Orbiter TPS. This was mentioned in previous sections of the report.

(b) There is no provision for draining the LOX and hydrogen from the ET except through the Orbiter feedlines and the propellant lines in the aft fuselage. The concern is that detanking during an emergency must be accomplished through a system which may be involved in the emergency. An emergency drain system is under consideration.

(c) There may be post separation contact between the ET and Orbiter because of undesirable motions caused by post-separation venting. This is under study.

(d) The flammability of the ET tank insulation and adequacy of the wire insulation are both under further review.

9.4 <u>Material to Update the Basic Information</u>

To assure the reader the most current information, this section has been established to include new, pertinent information developed by the Panel since the prior sections were written. This update adds, modifies or deletes previous data contained in this report.

9.4.1 Boundary Layer Tripping

Analysis of the "yoke" fitting on the forward Orbiter-to-ET attachment indicates that the fitting will cause the boundary layer to be tripped on the Orbiter (laminary to turbulent flow) earlier than desired. This will result in an increased heat transfer resulting in increased material temperatures of perhaps 80 to 100 degrees F. The extent of this problem is still under study along with possible redesigns of the yoke explosive bolt hardware.

9.4.2 Implementation Of Range Safety Requirements

The current design approach is to mount two conical shaped charges in the intertank between the LOX and LH_2 tanks, along with the two antennas, two batteries and associated electronics. The development of a cost/effective method of implementing range safety is under study with the objective of establishing an acceptable level of hazard from Space Transportation System operations and determining criteria for employment of a full or partial flight termination system. Total system definition and ET design requirements are expected to be established by August 1976.

9.4.3 Thermal and Structural Loads

Since thermal analysis data will not be available to support the design of the TPS for the External Tank the TPS design must include margins for any surprises. This may result in excessive weights and additional expense for TPS development now and further changes may be required a year from now when the revised heating data becomes available. The latest structural loads data (April 1976) may cause serious impacts on

the current ET hardware, in the intertank, hydrogen tank and interface hardware. If load relief trajectories now under investigation do not reduce the loads, the weight impact may exceed some 300 pounds and affect many pieces of hardware already designed.

9.4.4 Ice Protection

There are more than 70 ET protuberances which can collect ice. Steps have been and are being taken to alleviate this problem. The application of spray-on insulation (SOFI) has been examined and can provide ice control for about 85% of the surface area (=584 ft^2) with about 83 ft^2 remaining to be covered. The application of the insulation in these areas is somewhat more complicated than that for the remainder of the External Tank. Tolerance of the Orbiter and tank to the ice/frost accummulations during pad operations and ascent portion of the mission are still under assessment.

9.4.5 Thermal Protection System (TPS)

CPR 488 which is a reformulated CPR 421 deleting the cobalt is currently being evaluated. Preliminary results indicate that either may be used to provide the needed thermal protection.

9.4.6 LOX Anti-Geysering System

The test setup at Martin Marietta Corporation division at Denver, CO, to test the efficacy of the anti-geysering system is now in the final stages of installation and checkout. Baseline flow testing is scheduled to start soon after July 1, 1976.

ATTACHMENT 9-1

The major challenges on the External Tank of safety significance are thermal insulation, ice formation, the use of teflon electrical wire insulation in the liquid oxygen tank, and provisions for control of reentry.

Response:

Thermal Insulation

(a) The nose of the LOX tank has been revised from a hemispherical to a double cone configuration to avoid bow shock reattachment on the ogive and thereby reduce the heating. Wind tunnel testing, analysis of thermal data and development testing of TPS materials on coupons and subscale tanks are continuing to characterize the TPS properties.

Ice Formation

(b) Tests have been run in the Eglin AFB environmental chamber using a 10-foot diameter tank insulated with CPR-421 of several different configurations. The specific objective of these tests is to determine for selected worst environmental conditions the thickness and density of ice/frost. Other objectives were: (a) to verify the searchlight concept as a method to prevent ice/frost formation on TPS surfaces and (b) to demonstrate the feasibility of using conductive paints to prevent ice/frost formation. Test data are being analyzed.

Teflon Electrical Wire Insulation

(c) During the Apollo 13 investigation, a test program was run (according to procedures outlined in NHB 8060.1A, Test 4) on the teflon insulated instrumentation wiring used in the Saturn vehicles. The results of this program showed: (a) that the Saturn harness insulation immersed in LOX could not be ignited by any electrical overload; (b) in gaseous oxygen, the Saturn harness could be ignited when overloaded by approximately 800 percent electrically; (c) in the unlikely event of ignition, fire would not propogate through the feedthrough connector at the tank wall because the connector pins, rated at 7 amps, would fail open preventing propagation to the other side. As a result, no changes were made in the Saturn stages LOX tank instrumentation wiring.

The smallest wire in the ET will be No. 22 (except for 1/2-mil platinum wire in loading and liquid level sensors). Maximum design current for the No. 22 wire is 2 amperes. The maximum current into the tank under any single failure in sensor or signal conditioner is 1.5 amps. The duration of current will only be long enough for the 1/2 mil wire in the tank or circuit components in the signal conditioner to fuse (open).

The ET Project plans to conduct configuration tests using ET hardware and worst case conditions to assure no hazard exists.

Control of Reentry

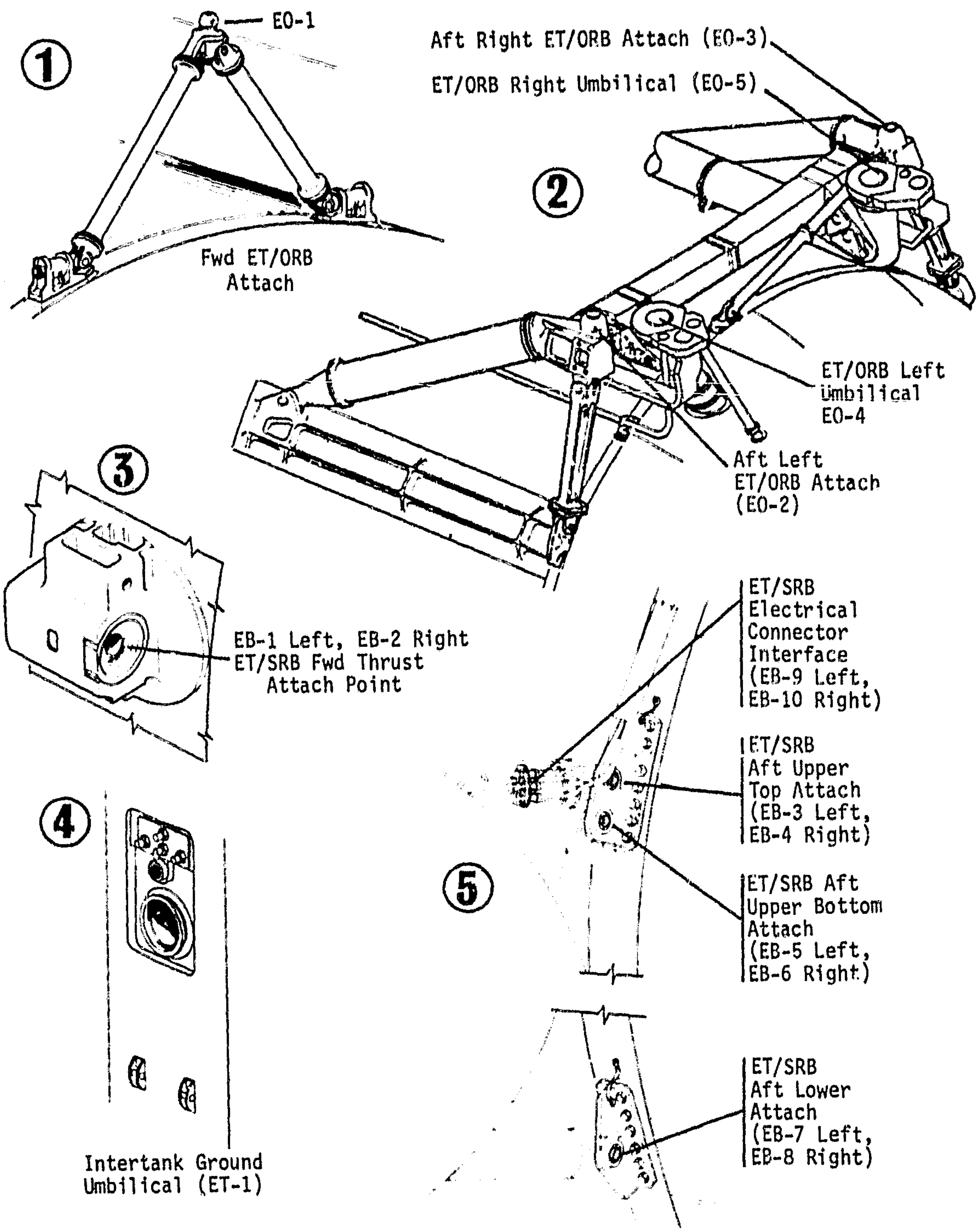
(d) The adoption of non-propulsive venting will ensure against premature breakup due to LOX and hydrogen tank ruptures. The baselining of a tumbling system utilizing a pyro valve with initiation at ET/Orbiter separation will provide the necessary controlled reentry.

TPS CONFIGURATION TABULATION

	TPS MATERIAL	THICKNESS-INCHES
Acreage		
Nose Fairing	SLA-561	0.35
LO_2 Vent Louvers	SLA-561	TBD
Conduit Fairing	SLA-561	0.4
LO_2 Tank Ogive	CPR-421	Taper
LO_2 Tank Barrel	CPR-421	1.0
LO_2 Tank Fwd Bulkhead	CPR-421	0.5
LO_2 Tank Aft Dome	None Req.	-----
Intertank	CPR-421 / SLA-561	0.5
LH_2 Tank Fwd Dome	CPR-421	0.5
LH_2 Tank Aft Dome	CPR 421	2.0
LH_2 Tank Barrel	CPR-421 / SLA-561	1.0
Penetrations		
LO_2 Feedline	CPR-421	1.0
LO_2 Antigeyser Line	CPR-421	1.0
GO_2 Pressurization Line	None Req.	----
LH_2 Feedline	SLA-561/CPR	0.4/1.0
LH_2 Recirculation Line	SLA-561/CPR	0.4/1.0
GH_2 Pressurization Line	None Req.	----
Electrical Cable Tray	SLA-561	0.05-0.35
LH_2 Vent Line	CPR-421	0.5
LO_2 A/G Line Fairing	SLA-561	0.4
LO_2 Feedline Fairing	SLA-561	0.4
GH_2 Press Line Fairing	SLA-561	0.4
IT Conduit Fairing	SLA-561	0.4
Structural Attachments		
LO_2 Feedline (5)	None Req.	----
LO_2 Antigeyser Line (14)	SLA-561	0.4
LO_2 Press Line/Cable Tray-LO Tank (17)	Req. TBD	
GH_2 Press Line (15)	SLA-561	0.2
Instrumentation	TBD	
Interface Structure		
Fwd ET/ORB Attachment Strut	SLA-561(Fwd Face)	0.25
Aft ET/ORB Thrust Strut	SLA-561(Fwd Face)	0.10
Aft ET/ORB Vertical Strut	SLA-561	0.15
Aft ET/ORB Diagonal Strut	SLA-561	0.15
Aft ET/ORB Crossbeam Fairing	SLA-561	0.30 Fwd/Aft Face 0.20 Top/Bottom
Fwd ET/SRB Attachment	None Req.	----
LO_2 Line Aft Interface Attachment	Req. TBD	
LH_2 Line Aft Interface Attachment	Req. TBD	
Isolator Requirements		
ET/SRB Aft Attachment (4)	Glass Phenolic	0.4
ET/ORB Fwd Attachment (2)	"	0.5
ET/ORB Aft Vertical Attachment (2)	"	0.4
ET/ORB Aft Sway Attachment (1)	"	0.4
LO_2 Feedline Attachment (8)	"	0.4
LO_2 Pressurization Line/Cable Tray Antigeyser Line Attachment (14)	Glass Phenolic	0.5
LH_2 Pressurization Line Attachment (15)	"	0.5
Miscellaneous Areas		
Intertank Forward of SRB Attachment	CPR-421	1.0
Intertank Forward of ORB Attachment	CPR-421/SLA-561	0.5/0.1
Intertank Umbilical Plate	None Req.	----
Intertank Umbilical Plate Cutout	SLA-561	0.2
LH_2 Tank Aft of Fwd ORB Attachments	CPR-421/SLA-561	1.0/0.2
Acreage Around Structural Attachment	SLA/CPR	0.1/ Variable
I/T Vent & Surrounding Area	SLA/CPR	TBD

FIGURE 9-1

EXTERNAL TANK ATTACHMENT HARDWARE



10.0 SOLID ROCKET BOOSTER

10.1 Introduction

Two solid rocket boosters (SRB's) burn in parallel with the Orbiter main propulsion system to provide initial ascent thrust. Primary elements of the booster are the solid rocket motor, forward and aft structures, the thrust vector control (TVC), operational flight instrumentation and recovery avionics, separation motors and pyrotechnics and recovery parachutes. Each SRB will weigh in excess of one and a quarter million pounds.

The major milestones for the SRB project provide a perspective on the current status of the program and the work ahead:

a. Delivery of the first machine finished case segment to Thiokol for filling is scheduled for September 1976.

b. The firing of the first solid rocket motor as part of the development test program is to be completed in July 1977.

c. The SRB Critical Design Review (CDR) is to be held in May 1977.

As further background the response from the Shuttle organization to the Panel's last Annual Report on the SRB is included as Attachment 10-1.

For the purposes of both description and data reporting, the SRB section of the report is divided as follows: Project Management, Solid Rocket Motor, Booster Separation Motors, Structures, Thrust

Vector Control, Electrical/Electronics/Instrumentation, Recovery Equipment, Range Safety/Flight Termination, Ground Support Equipment, Major Ground Tests, and Development Tests.

10.2 Project Management

The SRB overall design and control is currently being done by MSFC. The project management system utilized by NASA and its major SRB contractors is similar to that used on other elements of the Shuttle program. There are quarterly reviews conducted for NASA management and technical personnel, with the most recent one held on April 1-2, 1976 at the MSFC. Periodic design reviews for the major components of the SRB are conducted about once a month. Telecons and special meetings are a normal part of the technical management and working engineer system. The review system also includes integration reviews and program level reviews as required.

Recent additions to the list of major contractors working on the SRB include:

a. McDonnell Douglas Astronautics Company will provide the structures subsystem.

b. United Technologies, Chemical Systems Division, will provide the Booster Separation Motors.

c. Moog, Inc., Controls Division, will provide the Thrust Vector Control Actuator.

(d) Bendix Company of Teterboro, New Jersey, will provide the Integrated Electronic Assembly.

The Martin Marietta Co. has been selected as the recovery system contractor. Plans are underway to acquire the Booster Assembly Contractor (BAC). The intent of MSFC is to phaseover the logistics and operations planning as well as other assembly integration tasks to this contractor starting in the last half of 1976. The RFP has been issued and a contractor will be selected around mid-year.

10.3 Observations

10.3.1 Weight

The SRB weights are of course important. Since there are two units weight increases on the SRB have to be doubled to appreciate their impact on the total Shuttle. The table below shows the weight statistics:

SRB x 2 =	365,454	pounds inert specification control weight
=	357,738	pounds is the current inert weight
=	7,716	pounds margin
=	2,586,034	pounds total control weight
=	2,220,580	pounds solid propellant weight

The available margin for the SRB's is roughly 2.2% on the inert weight. This is a somewhat tight figure at this time considering the

possible growth due to design additions and modifications resulting from the development test program.

10.3.2 Solid Rocket Motor (SRM)

The solid rocket motor is more than 125 feet long and 12 feet in diameter. The solid propellant is cast and cured in four casting segments which are transported by rail to the launch site where they are to be assembled into the finished motor. The SRM propellant is the same type as that used in the Poseidon and the First Stage Minuteman motors. The nozzle is nearly 13 feet long and is also 12 feet in diameter at the exit. It weighs nearly 11 tons. A key feature of this nozzle is a flexible bearing constructed of alternate layers of elastromeric rubber and steel which permits the nozzle to be gimbaled and deflected for attitude control of the Shuttle System during ascent portion of the mission. The SRM igniter mounted in the head of the motor weighs about 660 pounds and is larger than many tactical rocket motors. The igniter consists of a safe and arm device, a pyrogen initiator, and the main pyrogen igniter. The SRM's are designed to burn for about two minutes carrying the Shuttle cluster to about 25 miles altitude after which the SRB will separate, parachute to the ocean for recovery and reuse.

The SRM is deep in the phase of component design, development,

and testing. The SRM Critical Design Review (CDR) is set for mid-1977. The ground tests of interest include the following:

(a)	Subscale Flexible Bearing (Nozzle)	Completed Successfully
(b)	Prototype Flex Bearing Tests	December 1976
(c)	Ignition System Development & Qual	February 1977
(d)	Ignition Safeing and Arming D & Q	Mid-1977
(e)	Case Hydroburst	September 1977
(f)	Nozzle/TVC Confirmation	December 1977
(g)	Railroad "Hump" Test	Mid-1978

To accomplish the program the following types and quantities of motors are being produced: four development motors, three qualification motors, and five ground test motors. Two of the ground test motors are inert - two are empty and one is for structural test. In addition, the present schedule includes six flight motors.

The motors will be used in the following test schedule:

(a)	Development firings	Number 1	July 1977
		Number 2	September 1977
		Number 3	February 1978
		Number 4	April 1978

On the Number 2 and 3 firings the same refurbished case will be used. A refurbished nozzle and flexible bearing will be used on the Number 4

C-4

development firing while the number 3 firing will use a non-refurbished or used flexible bearing.

(b) Qualification Firings	Number 1	July 1978
	Number 2	August 1978
	Number 3	December 1978

On the Number 1 and 3 qualification firings the same refurbished case will be used.

10.3.2.1 Design Loads

The magnitude of the flight and water impact loads and the resultant attrition rate or loss of the SRB's during recovery is of concern because of the effect such losses have on the cost per flight figures for the Shuttle mission. The design load considerations for reuse of the SRB directly affect the SRM. The SRM case is designed for the maximum expected operating pressure. The nozzle and aft skirt are subjected to support loads from the launch pad, reentry acoustic (organ pipe effect). The aft end of the SRM is designed for water impact and the water cavity collapse loads after the rocket strikes the water.

The major concern regarding design loads has centered on the water impact loads. Originally, the project anticipated a water impact load based on 100 ft/sec vertical velocity. As a result of analysis and model tests by MSFC, their contractors, and other federal agencies,

the project has determined that a vertical velocity of 85 ft/sec is more realistic. This means a reduction in total program cost, reduced risk of losing an entire SRB during entry, and a more acceptable weight margin. The change in expected attrition rates is shown in the following table:

Water Impact Attrition For 85 ft/sec

	85 ft/sec	100 ft/sec
Aft Skirt	7.2%	20.0%
Aft SRM Segments	1.3	9.5
Forward SRM Segments	1.9	1.3
SRM Nozzle	3.6	7.0
TVC Actuators	8.3	12.5
TVC Power Supply	3.6	10.0

No attrition analyses have been done on a configuration using less than three (3) parachutes.

10.3.2.2 Case Heat Treat

Shuttle SRM components are unique in that they will be recovered and reused again and again. This requirement involves complex strength requirements in both material fracture toughness and tensile properties. Considerable effort is being expended in baselining a heat treat process to achieve the proper mechanical properties. The work so far shows that the heat treat profile used

produces acceptable tensile properties in all materials tested to date and the heat treat has produced acceptable toughness properties with the exception of one questionable sample. As a result the baseline heat treat profile appears acceptable for meeting the SRM case material mechanical requirements.

10.3.2.3 Corrosion of the SRM Case

Essentially, the SRM is a segmented stack of large cylindrical shells made from D6AC steel, joined together by a clevis arrangement, and fastened with MP35N pins. The SRM case design is such that it should prevent corrosive attack, accelerated galvanic corrosion, crevice corrosion, and stress corrosion. The optimum scheme for joint protection will be determined based on results from tests where parts are immersed in flowing seawater. The majority of the case is to be coated with organic films of proven protective capability and the joints will use a sealant and an organic barrier combination.

It has been recognized that the female portions of the clevis joints present the greatest uncertainty regarding protection. This uncertainty has been taken into account as far as possible and such joints will receive special attention during assembly and be subjected to non-destructive test techniques.

10.3.2.4 Thrust-Time Shaping

Thiokol Chemical was directed by MSFC to provide a support study on SRM thrust-time (performance) shaping to the Rockwell Internationa, Space Division. This thrust-time study involved grain design and inhibiters. The studies indicated that through the performance-shaping it would be possible to desensitize key ascent flight parameters and reduce flight load problems. These requirement changes occurred after the base-lining of the SRM design and therefore will have an effect on the SRM schedule, cost and facilities. The changes to the SRM propellant will have only a minimum impact on the SRM program.

10.3.2.5 Nozzle Flexible Bearing

The SRM nozzle design is shown in Figure 10-1. The flex bearing is a nozzle subassembly which gives a $\pm$ 8 degree omnidirectional thrust vector control capability to the SRM. Sub-scale testing of this flex bearing indicated material problems that would have to be resolved prior to the fabrication of the full-scale unit scheduled for testing at a later date.

The problem appears to be in the use of the elastomers (rubber material) and their stability during processing of the bearing itself in the hot-mold process. Studies to date have identified four candidate elastomers that appear suitable for SRM flex bearing use so that there should be no real difficulty in building and success-

fully testing a prototype bearing.

10.3.2.6 Ignition System

The ignition system is large and somewhat sophisticated. Figure 10-2 shows both the igniter assembly which has a large quantity of propellant and the safe and arm unit which is a motorized assembly to open and close the ports used to ignite the system. Testing and development of this component is currently in full swing and will be monitored by the Panel.

10.3.3 Booster Separation Motor

To meet the SRB separation requirements listed below it was decided that small rocket motors would be best in translating the SRB away from the Orbiter and External Tank at the desired time in the Space Shuttle ascent trajectory.

These requirements include the following:

(a) Separation of the SRB should preclude damage to or recontact with other Shuttle elements during or after separation.

(b) Exhaust gases from the rocket motor's separation systems should not cause damage to the remaining Shuttle elements which would require repair or replacement of the Orbiter TPS.

(c) Installation of the separation motors shall be in the SRB nose frustum and SRB aft skirt.

(d) Release of all structural attachments shall occur within 30 milliseconds and the thrust of each set of BSM's shall reach 55,500 pounds of thrust in each set within 30 to 135 milliseconds of the separation command.

(e) The design should provide for safe separation for angles of attack and sideslip over a range of ± 15 degrees including the rates and dynamic pressures which follow. The maximum dynamic pressure shall be 75 psi and the maximum rates shall be ± 2 degrees per second in pitch and yaw. These rates and dynamic pressures will be sensed or computed by the Orbiter and when exceeded shall inhibit the separation of the SRB's.

The status of motor development indicates that there are no major concerns on this project. The propellant has been baselined and characterized. Detailed design drawings and preliminary analysis reports have been completed. The PDR was conducted in February 1976 and motor case fabrication has been initiated. Further definition of the interface between the Booster Separation Motors and the SRB/ET/Orbiter are required. The exact nature of this definition is not known at this time.

By mid-1976 testing of the igniters should be completed. The first four test motors should be completed by mid-January 1977. Qualification is set for 1977 and the delivery of the flight hardware is set for 1978.

10.3.4 Integrated Electronic Assembly (IEA)

The IEA system utilizes orbiter power for the Orbiter data bus. It provides support to the following SRB functions:

(a) Thrust Vector Control (TVC) Subsystem

(b) Development Flight Instrumentation

(c) Range Safety System

(d) Recovery System

(e) Shuttle Flight Control System (through the Orbiter)

(f) Separation System

(g) SRM

Figure 10-3 shows the IEA unit in simple detail. There are actually two types, one mounted in the forward skirt and one mounted with the aft External Tank attach ring. Both are watertight. They weigh about 190 pounds ready-to-go and are about 12" x 13" x 45" in size. The PDR was completed in December 1975. Mockup vibration testing is underway, and stress corrosion susceptibility studies have been completed. The only concern is the lead time required for the procurement of the watertight connectors for the units.

10.3.5 Structures

This area includes all of those structural items that tie the various subsystems together - the aft skirt, ET struts and attachments, systems tunnels, forward skirt, forward ordnance ring, tow-

ing pendant, altitude sensor assembly, frustum assembly, nose cap assembly, and flotation installation. This program is in a very early stage and will be reviewed by the Panel as it evolves in the future.

10.4 Range Safety System

This has been partially discussed in the section devoted to the External Tank. Therefore only that portion of the Range Safety Flight Termination system dealing with the SRB is covered here. It was determined that a conical shaped charge was no longer needed in the nose cone of the SRB, and that the SRB would use a linear-shaped charge along 10% of the SRM portion of the SRB. Such a charge would be placed on either side of the SRM. This system is to be applied to both the SRB's. The specified requirement in Volume X, JSC 07700 will now state: "The SRB's shall be provided with ground-commanded systems to destruct the SRB's. System components shall be reusable where cost savings will result."

Trade studies are currently being conducted with regard to the use of a redundant open-loop initiator versus a closed-loop dual initiator. Closed-loop refers to the initiation of the charge from both ends, while open-loop means setting the train off from only one end. The Panel will follow the evolving system to assure that the decisions being made receive appropriate management attention.

10.5 SRB Reuse

The reuse requirements "drive" the design of the SRB and its components. The total number of times the components are used is as follows:

(a)	Structures (excluding nose cap and thermal shield)	40
(b)	Thrust Vector Control	20
(c)	Electrical and Instrumentation (excluding batteries, lights, exposed cables)	20
(d)	Recovery System (parachutes, et.al.)	10
(e)	Solid Rocket Motor (except as below)	20
	Flex Bearing Materials (elastomers)	10
	Nozzle Ablator Material	1
	O-Ring Seals	1
(f)	Pyrotechnic Devices	1
(g)	Booster Separation Motors	1

Specific design features to assure reusability include the use of protective coatings over a relatively small percentage of the SRB, a weld-free SRM case, watertight compartments for electrical/electronic/instrumentation installations, stiffening rings for water impact loads, flexible aft-skirt heat shield, and similar design items. To achieve the design requirements a good deal of effort continues to be expended on the case heat-treat process, Thermal Protection Subsystem materials, the paints and sealants, and flotation materials. The status of these areas is to be monitored during the Panel's future reviews.

Decisions on the reuseability of a piece of hardware will, of

course, depend on what wears out and what causes an item to be considered worn-out. The point at which a piece of hardware is considered worn out is not a discretely defined point but will result from the cumulative effects of exposure to environments and handling. Loss from water impact damage is the most significant attrition factor. Retrieval operations once the SRB is in the water poses the next major possibility for losing it since there can be problems locating the vehicle or towing it; also, there is the possibility of storms severe enough to preclude retrieval or damage the vehicle while in the water. Other factors that would preclude reuse of specific items include:

(a) Structures - wearout or damage due to accumulated dings, dents, and corrosion.

(b) Recovery - excessive parachute ribbon damage from inflation and retrieval.

(c) Electrical and Instrumentation - Mechanical failures, e.g., cracked solder joints, broken wires, "drift" of piece parts.

(d) TVC - Failures in the actuator rod end bearing; the power supply flex hoses, valving, exhaust ducting, pumps; as well as general corrosion.

(e) SRM - Accumulated abnormal loss of metal from grit blast

preparation during refurbishment.

10.6 Test Program

The SRB will be qualified at the motor level (FRM) in addition to the normal qualification of components. Because it is a recoverable and reuseable item there are special tests not required on other elements of the Shuttle program.

The common structural tests conducted on all segments of the Shuttle vehicle are a part of the SRB test program as well. These include static structural tests to verify material selection, validate stress analyses and design margins, etc. Dynamic model surveys will provide data on dynamic model analysis. Separation tests, including full-scale tests of the separation motors, will verify design and performance. The SRB component environmental certification test requirements and methods are included in the MSFC report "SRB Component Environmental Certification Test Requirements and Methods" SE-019-067-2H. Rather than discuss the details of this program in this report the reader should examine the MSFC test document itself.

Finally, requirements for retest of the refurbished hardware is crucial to this program.

The test area will be a subject for further examination to assure that the confidence level achieved through the test program is of sufficient degree to support the first Orbital Flight Test

as well as subsequent missions.

10.7 Fracture Control

There is a very detailed fracture control program now in full operation. It is understood that fracture control requirements have been included in all procurement packages along with a requirement for fracture control boards. On October 8, 1975 the first formal meeting of the MSFC/SRB Fracture Control Board (FCB) was held. The SRB/FCB staffed by MSFC is responsible for the overall SRB program. In addition there is an SRM Fracture Control Board established and staffed by Thiokol which has been in operation for some time.

To illustrate the work of the MSFC Board the meeting on December 10, 1975 reviewed the Booster Separation Motor (BSM) Fracture Control Plan. This review covered the FCB's organization and responsibilities and the implementation of the fracture control plan at the contractor with particular attention to part selection logic and the design/analysis, fabrication and test procedures.

An example of the hardware placed under fracture control is seen in the Thiokol FCB activities. Thiokol has reviewed the various parts which make up the SRM and, based on fracture control selection logic, has made a determination of the fracture critical items. The items which have been identified for fracture control are the case segments, igniter chamber and adapter, and the nozzle

stationary shell and flex shims. These items, in most cases, have high tensile stresses. However, the selection process gave particular attention to the impact on mission success and program schedule if the hardware should fail and have to be replaced. The clevis joint and the basic-part membranes are the most significant items on this list. More detailed fracture mechanics analyses have been performed on such parts to determine the expected flaw growth, critical number of cycles, stresses, and test proof factor. In particular, testing has been completed for the clevis joint to determine its mode of failure. The testing and analysis completed to date have shown that these parts can withstand significantly more cycles and higher stresses than expected during the actual mission.

In additon to the fracture mechanics analysis, some stress corrosion work has been completed. Areas of investigation include effects of material exposure to sea water, coatings, heat treating effects, and fracture toughness determinations considering temperature effects. This work is to be supplemented with testing on forging sections, hydroburst testing, etc.

A point brought up during MSFC FRB discussions with Thiokol is important. They were asked what they would do differently in testing, traceability, inspection, etc., if a part was not under fracture control. The answer was that all parts of the SRM would be

subjected to the same rigor regardless of fracture control disposition. The primary difference is the level of review for any item that is out of specification or is considered to have a discrepancy. The MSFC/FCB is in the process of evaluating the need to place the SRM propellants under fracture control. Thiokol has not considered this necessary at this time.

10.8 SRM "Burn Through"

Burn-through relates to the loss of case integrity because the propellant burns a hole in the case. Previous solid rocket experience, particularly on military rockets, has been examined and applied to the design of the Shuttle SRM. Potential "burn-through" failure modes identified during the Panel's review were:

(a) Propellant grain defects.

(b) Nozzle ablatives.

(c) O-ring seals and clevis joints.

(d) Internal case insulation.

(e) Propellant inhibitor.

(f) Forward case segment igniter bolt holes.

(g) Propellant-liner-insulation-case bonds.

The design appears to be based on demonstrated concepts to preclude case burn-through and there are adequate safety factors of 2:1 or higher to accommodate uncertainties. Extensive component

testing will be performed to validate this design approach.

10.9 SRB Hazards

The following listing is provided to indicate the types and numbers of hazards on the SRB. Many of these hazards have been eliminated; others have been accepted by management based on a thorough review of the problem. Some are still being worked.

- SRB ignition overpressure
- Late ignition of one of the SRB's
- Failure of fore or aft BSM's
- Public hazard from impact of SRB (in work)
- Contingency abort capability with SRB (in work)
- Emergency escape in flight
- SRB mechanical safe-arm device to be enabled in the VAB (in work)
- Excessive q-alpha and/or q-beta on Shuttle ascent

10.10 Lightning Protection

SRB equipment requiring protection includes the pyrotechnics, TVC sensors and switching circuits, integrated electronics assembly plus all exposed electrical cables. The governing design document is the JSC-07636 Rev. A, dated November 4, 1975, "Space Shuttle Program Lightning Protection Criteria Document." Briefly the SRB nozzle

lightning design measures being taken include: single point ground on power circuits, use of twisted wire pairs, 2 $\pm$ 1/millisecond delays for switching functions, cable tunnel protection, multi-grounded overall shields on ordnance cables, and tests. This area will continue to be monitored by the Panel.

10.11 Addendum

This is the period in the SRB development when requirements are still in evolution. A revised SRB Verification Plan (Volume IV, SE-019-019-2H) has been released since the earlier sections were written. Some of the latest updates are to assure complete records on test programs, procedures and results.

The "SRB Component Environmental Test Requirements and Methods" was issued in December 1975 as SE-019-067-2H. It establishes the detailed environmental test requirements, test methods, and test criteria to be utilized in the environmental acceptance and certification testing.

The SRB safe and arm device critical design review was conducted at the subcontractor's site in June 1976. Final closeout for the resulting actions is scheduled for July/August 1976.

ATTACHMENT 10-1

The Solid Rocket Booster is in an early stage of development. Critical areas must be monitored closely for the earliest possible detection and resolution of problems to assure that trade-offs provide for the maximum Space Shuttle system safety. Such areas include recovery and re-use of the booster.

RESPONSE: Space Shuttle Program Management and especially the SRB Project Manager are sensitive to the areas affected by the reuseability concept. Special analyses are continuing to maintain high reliability of the components and subsystems which are affected by planned reuse. In addition to the activities within the SRB project at MSFC, a special SRB review function was established within the JSC Space Shuttle Systems Engineering Office to provide an independent assessment of the SRB design and development activities. This function includes review of subsystem designs (structures, avionics, recovery, TVC, etc.) as well as the refurbishment planning. This review group is involved in source selections for these subsystems all the way from design through RFP preparation to participation in SEB's. They are currently assessing the design criteria for recovery system parachutes and the planning for the parachute drop test programs.

It is important to note that hazards to personnel involved in the water retrieval of the booster and parachutes are no longer a major concern, since divers are not now planned for the nozzle plugging operation. The Naval Undersea Center is developing an underwater remote controlled device to accomplish this without diver participation.

In addition to these independent review activities, study teams have been formed to establish refurbishment operations requirements for returning the SRB reuseable components to a flight acceptable condition.

FIGURE 10-1

SRM Nozzle Design

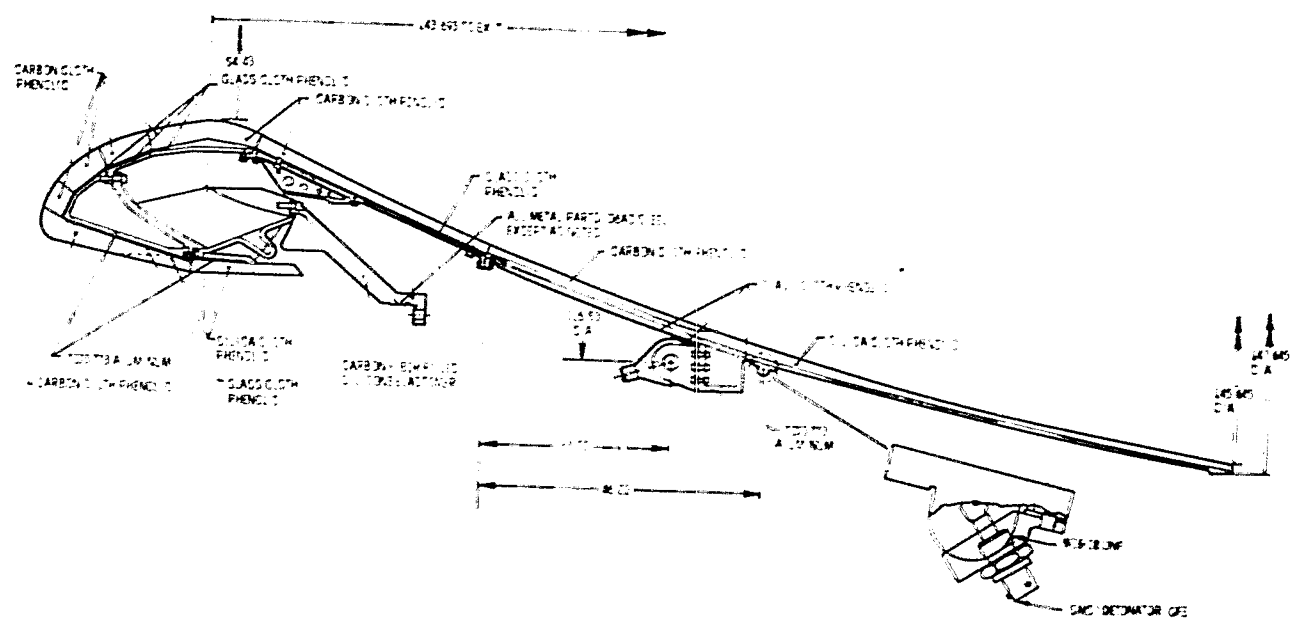


FIGURE 10-2

IGNITER ASSEMBLY

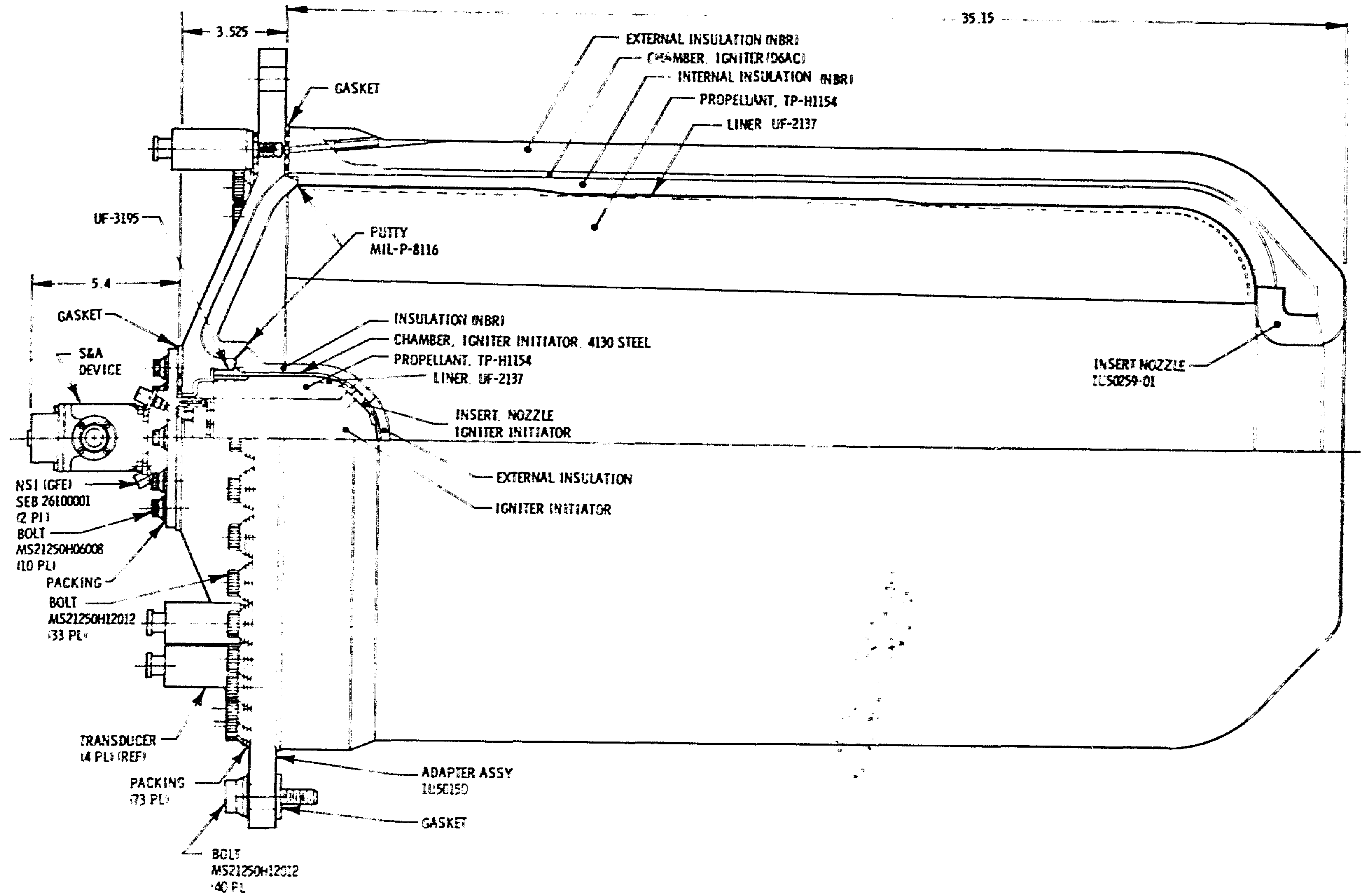


FIGURE 10-3

INTEGRATED ELECTRONIC ASSEMBLY ISOMETRIC